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Aurora. *Frontispiece.*

(From Guillemin's "Electricity and Magnetism.")

TERRESTRIAL MAGNETISM

AND ITS CAUSES

A Contribution towards the elucidation of the problem

By F. A. BLACK.

London
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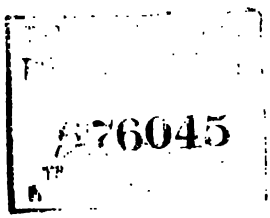
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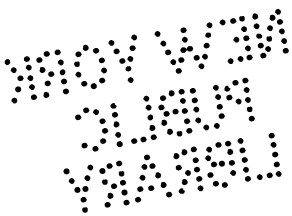

PREFACE.

It is with much diffidence that I have decided to issue the following pages to the judgment of physicists, and others practically interested in the subject treated. As an amateur, dabbling in a scientific subject of peculiar complexity, and handicapped by the want of ready access to detailed and recent information, such diffidence is natural. I have been influenced in my decision by two reasons. In the first place, if the theory propounded is in the main correct and novel, it is only right that publicity should be given to it, and, in the second place, if the theory is incorrect, or in the main incorrect, its promulgation may, nevertheless, further the progress of scientific investigation by directing attention to certain matters connected with the subject which appear to have hitherto been overlooked, or comparatively ignored.

I have endeavoured to show that by the acceptance of the modern speculative hypothesis that the space surrounding the Earth, beyond the enveloping atmosphere, is permeated by a medium of an electrical character—an hypothesis put forward in relation to subjects unconnected with terrestrial magnetism, and which must necessarily from its nature be speculative—a reasonable and satisfactory explanation can be obtained as to how it comes about that the Earth is a magnet.

This being granted, I have ventured to submit that many of the puzzling peculiarities connected with the various phenomena relating to terrestrial magnetism may be—at

least to some extent—explained, by giving due weight to (1) the peculiarities connected with the nature of the Earth's magnetization, and (2) the peculiarities connected with the material structure and motions of the body magnetized—that is, the Earth itself.

Whilst the reasons submitted appear to myself to be of weight, others will doubtless be able to detect some fallacies. The subject has so persistently eluded the discovery of its governing laws that this must be looked for.

I have to express my earnest hope that this little contribution towards the elucidation of a difficult subject may really prove helpful in that direction.

I have to acknowledge my indebtedness to my friend, Mr. Arthur H. Mackenzie, M.A., B.Sc., South Kensington, for the working of the problems in spherical trigonometry, which are embodied in the Appendix.

I have also to acknowledge my indebtedness to the Publishers for valuable assistance and suggestions in connection with various details.

FREDK. A. BLACK.

53 ACADEMY STREET, INVERNESS.
JAN. 1905.

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TERRESTRIAL MAGNETISM

AND ITS CAUSES.

CHAPTER I.

THE NATURE OF THE PROBLEM.

THE phenomenon of terrestrial magnetism is still one of the mysteries of science, although the fact that the magnetic needle of the compass points approximately north and south, has been known for ages.

The origin of the compass cannot, indeed, be traced with any certainty. There is reason to believe that the Chinese knew something of the polaric property of loadstone more than two thousand years before the Christian era. They, according to their traditions, used the compass from the most remote antiquity to guide them in their travels. They had an invention which they called a "south-indicating car," in the upper part of which was set a magnetic needle, floating freely on water, and so adjusted as to move the arm of a small figure, and cause it to point constantly towards the south. This invention is traditionally supposed to have been in use more than a thousand years before the commencement of our era. At any rate the Chinese in all probability had some know-

ledge of the directive tendency of the magnetic needle three thousand years ago.

The power of the loadstone, to magnetise iron, is for the first time clearly referred to in a Chinese dictionary, which was finished in 121 A.D., where the loadstone is defined as "a stone with which an attraction can be given to the needle." The first mention of the use of the compass in navigation, occurs in a Chinese encyclopædia, in which it is stated that under the Tsin dynasty, or between 265 and 419 A.D., "there were ships directed to the south by the needle." Sir G. T. Staunton in his "Embassy to China," which was published in the closing years of the eighteenth century, refers to the early acquaintance of the Chinese with the property of the compass to point southwards, and continues, "The nature and the cause of the qualities of the magnet have, at all times, been subjects of contemplation among the Chinese. The Chinese name for the compass is *ting-nan-ching*, or needle pointing to the south, and a distinguishing mark is fixed on the magnet's southern pole, as in European compasses upon the northern one." The number of points of the compass, according to the Chinese, is twenty-four (instead of thirty-two as is the case with us), and these are reckoned from the South Pole. The form of the compass in use in China is also, according to Mr. F. H. Butler, different from that employed in Europe. He states that "the needle is peculiarly poised, with its point of suspension a little below its centre of gravity, and is exceedingly sensitive; it is seldom more than

an inch in length, and is less than a line in thickness." As Mr. Butler remarks, "it appears thus sufficiently evident that the Chinese are not indebted to Western nations for their knowledge of the use of the compass."

The compass was, it is supposed, introduced into Europe in the eleventh or twelfth century A.D., in the original form of a needle floating on water, and it was not until the latter half of the fourteenth century that the balanced needle came into use.

The honour of having invented the compass has been claimed by some Italians for their countryman Flavio Gioja, a native of Amalfi, who lived in the fourteenth century, but it is generally believed that he can be credited only with some important improvement on the instrument, possibly with the balancing of the needle on a pivot, in place of having it floating on water, or suspended by a thread. Undoubtedly the compass was in use in China long before his time.

Notwithstanding their knowledge of the directive tendency of the needle for so many centuries before its introduction into Europe, the Chinese had no knowledge of the fact that every magnet has *two* poles. They apparently regarded only the direction of *the marked end* of the needle which they expected to indicate the south, and they could not understand why it occasionally happened that this end turned towards the north instead of the south. They magnetised their needles by rubbing them with loadstone, and the distinction in the effect produced in different needles was an insoluble puzzle. A Chinese author

(11th cent.), quoted by Biot, describes the process of magnetization and its results. He says "those who perform the trick rub the needle with a magnet stone; then it will mark the south; it will, however, decline always a little towards the east. It does not exactly indicate the south. When such a needle floats on water it is very much agitated. If one's finger nails simply touch the edge of the basin where it floats, they throw it into agitation. It is better to suspend it in order to manifest its virtue as much as possible. This is the method,—take a thread out of a new skein of cotton, and stick one end of the thread to the exact middle of the magnet, with a piece of wax as big as a mustard seed. Then hang it in a place free from draughts. The needle will then point steadily to the south. Among these needles obtained by rubbing, there are always some which mark the north. Our conjurers always have some which point south, and some which point north."

This quotation makes it evident that the Chinese had discovered by the eleventh century A.D. that the direction of the needle was not exactly towards the true north and south in that locality, and possibly they may have discovered at this early period that its direction was subject to slight variation, although, as Staunton points out, "the sphere of Chinese navigation is too limited to have afforded experience and observation for forming any system of laws supposed to govern the variation of the needle."

The needle of the compass is commonly said to

point north and south, but it is in comparatively few places that this is literally correct. It has not been the case in London since the year 1657. Before that year, the marked end of the needle pointed eastward of north, and ever since then it has pointed westward of north; but this westerly "variation" as it is called, reached its maximum, which was about 24½ degrees in 1818, and has since then been slowly diminishing year by year. The discovery that the needle was subject to variation in direction has been attributed by some to Columbus, but many authorities suppose the fact to have been known long before his time. In fact, this discovery also is claimed for the Chinese, and is said to have been made in the eleventh century of our era.

Although it thus appears that the fact that the magnetic needle has a directive tendency has been known for many centuries, and the fact that its direction is subject to gradual variation has been known for at least three hundred years, we are still without any satisfactory explanation of these facts. There can be no doubt that the varying direction of the needle is really subject to natural laws; but, though the discovery and elucidation of these laws have been for centuries a matter of patient investigation, no satisfactory explanation has yet been arrived at.

The very mystery which attaches to the whole subject has proved alluring, and many explanations have been forthcoming. Sir Humphrey Gilbert, a distinguished English navigator and discoverer of the

time of Queen Elizabeth, conjectured the existence of a large magnet inside the earth, whose poles were near the geographical poles. Halley, the celebrated Astronomer Royal, published in 1683 a "Theory of the Variation of the Magnetical Compass," in which he endeavours to account for the action of the compass by the supposition of the earth being a great magnet, having four circulating magnetic poles or points of attraction. This theory is referred to in a recent work as "ingenious though unsatisfactory." Barlow, who was Professor of Mathematics at Woolwich Royal Military Academy about the middle of last century, explained the observed facts by supposing the existence of electric currents passing around the earth's surface from east to west. One theory suggests the existence of a small magnet of great power inside the earth, another the existence of two magnets, but it is admitted that even if either supposition would explain certain facts, each would leave many facts absolutely unexplained. Many other complicated explanations have been given, but have failed to receive general acceptance.

It has in our own day been discovered that when the sensitive needles of the observatories exhibit the tremulous agitations characteristic of what are called "magnetic storms" there are invariably at, or about, the same time, more or less brilliant displays of aurora and conspicuous spots on the sun, and it has been demonstrated that if any two of these phenomena occur the third must also occur. If spots on the sun

become apparent and aurora is visible, there have been, or there will be, magnetic storms. If there are sun spots and magnetic storms, we may conclude that the aurora is more than usually conspicuous, whether it is visible in our own part of the earth or not. If we have aurora and magnetic storms, there must be sun spots. That there is some connection between these three natural phenomena is generally agreed, but as to the nature of the connection, we have, as yet, no definite and satisfactory explanation.

The mystery of the compass is still a mystery, made the more interesting by a chance illuminant.

At present magnetists are chiefly engaged in accumulating observations which will be available for the future complete elucidation of the subject. To the questions, *why* does the magnetic needle point approximately to the north and south, what causes the needle to vary in its direction, what are the causes of magnetic storms, and what is the nature of the connection between auroræ, magnetic storms, and sun spots, no satisfactory answer has yet been given.

In former generations the explanation of the existence of terrestrial magnetism was generally looked for in terrestrial sources; but, latterly, the tendency has become more general to seek for the explanation in extra-mundane sources, and at present opinion is divided as to whether these sources are of solar or cosmic origin.

Such is the problem at present engaging the attention of magnetists all the world over.

CHAPTER II.

The Orbital and Diurnal Movements of the Earth.—The space-filling medium and its nature.—The Sun's action on the Earth through this medium.

In considering whether, as is now generally believed, terrestrial magnetism is really originated by causes outside the earth, the first question which presents itself is, whether the earth in its axial and orbital movements encounters any medium by which it may be affected. The earth moves in its orbit at the inconceivable average speed of 18½ miles a second, while it rotates on its axis at such a speed as results in a complete revolution every 24 hours. By the orbital movement *every portion* of the earth is, of course, carried onward at the *same* speed; but by the diurnal rotation different localities on the surface are carried through space at various rates of speed, according to their geographical latitude. As the circumference of the earth at the equator is about 25,000 miles, every spot on the equator is carried daily through 25,000 miles by the axial rotation, being a speed of about 17⅓ miles a minute. On the other hand the geographical poles are not carried through space at all by the daily rotation, and, between the equator and

the poles, the speed of the rotatory displacement continuously decreases as the latitude increases.

We have now to consider whether in these movements of orbital and diurnal rotation there is any influence brought to bear upon the earth through the medium of surrounding space.

If the space surrounding the earth were a vacuum, we could conceive of the earth being absolutely unaffected by its movements through it; but if the surrounding space is not a vacuum, then, no doubt, according to the nature of its constituents, it must in some measure influence the earth. It is, of course, evident that, if it is not a vacuum, the surrounding space can be occupied only by a peculiarly subtle medium, as otherwise the movements of the earth would necessarily in the course of ages be retarded, and ultimately brought to an end; while there appears to be no conclusive evidence that the orbital movement of the earth has appreciably decreased in rapidity from the earliest times.

The vague notion of the "ether" as an intangible medium pervading all space, has been common property since the days of Newton. In order to base various scientific theories, physicists have repeatedly found themselves obliged to *assume* the existence, in the space surrounding the earth, of a substance of extreme tenuity.

It thus came to be conjectured, and gradually accepted, that space cannot be an absolute void, and the tenuous substance, by which it came by degrees to be believed it was filled, became known as the "ether." Thus,

"ether" is a name given to the supposed space-filling medium, in ignorance of either its actual existence or its nature, the name being, it is believed, derived from the Greek word *αἴθω*,—I light up, I burn.

Although the presence of an "ether" in the surrounding space was thus merely conjectured deductively by scientists in the past, and although our ideas of the "ether" have continued to be rather vague and indefinite; recent investigations have tended to throw some light on the question as to whether interstellar space, or at least the space immediately surrounding the earth, is really permeated by an intangible medium, and have also, to some extent, given definiteness to the former vague notions regarding this supposed medium.

Astronomers believe that what is called "the Zodiacal Light" extends outwards from the sun to a distance greater than that which separates the earth from the great centre of the system. Professor Simon Newcomb of Washington, who is an authority on astronomical subjects, says that "up to the present time, the conclusions which can be definitely stated are somewhat general in their nature. The sun is surrounded by an exceedingly rare cloud of matter of very indefinite outline, lenticular in form, extending out somewhat beyond the orbit of the earth." The older astronomers such as Kepler, supposed the Zodiacal Light to be the atmosphere of the sun, but the weight of modern astronomical opinion appears to be against such a supposition. It is, however, agreed that this tenuous

substance, whether it is really the sun's atmosphere or not, extends outwards from the sun, beyond the greatest distance at any time separating our planet from the sun (which we may take to be 94½ millions of miles), so that in at least a portion of its orbital journey the earth probably moves through it, and thus, according to this view, the space immediately surrounding the earth is, at least to some extent, occupied by this "rare cloud of matter."

Chemists and physicists, however, have been the chief contributors to our knowledge regarding the surrounding space, and this principally in connection with investigations quite apart from our subject. These investigations have thrown much light upon the question of the nature of the conjectured space-filling ether, at anyrate in so far as our system is concerned.

Professor J. J. Thomson of Cambridge, in his studies of the Crookes tubes, found that the exquisite glow which appears when a current of electricity is sent through a tube is apparently due to minute particles shot by repulsion from one of its poles. These particles are heated to incandescence and travel at a speed of 50,000 miles a second, being about one-third of the velocity of light. Professor Thomson and his co-workers "found a way to measure their mass, and the charge of electricity they bear. The charge is the same as that of the particles which ferry electricity through a liquid, but their mass is but a thousandth part of that of the lightest atom known. What is

more striking than all is that they seem all alike. No matter what may be their source they have the same mass, the same charge, act exactly the same. The cathode—the pole from which they spring—may be of gold or lead, of copper or silver, it makes no difference. Moreover, it seems as if these cathode particles, as they are called, are streaming from everywhere—from the sun, from the tips of the leaves of a tree. Space seems to be swarming with them."*

Professor Thomson, following Newton's phraseology, called these particles "corpuscles," and, as, Mr. Carl Snyder remarks in his recently published volume, *New Conceptions in Science*, "It is rather bewildering to be told that these corpuscles may turn out to be electricity, matter, light, the aurora borealis, magnetism, chemical affinity, and various other trifles, all at once."†

Professor Thomson discovered that these particles bear a high electrical charge, and that a stream of them could be bent and deflected by a magnet as if it were a piece of iron. These "corpuscles," have introduced into the realm of science an entirely new conception, which is that *electricity is really atomic in structure.*

Professor Crookes, in the course of his investigations, found that while as a general rule the higher the degree of exhaustion in the Crookes tubes the more readily could a current of electricity bridge the

* *New Conceptions in Science*, by Carl Snyder, p. 94. † *New Conceptions in Science*, p. 138.

empty space, yet a degree of exhaustion could be reached at which the conductivity began to grow less again. From this it has been inferred that a perfect vacuum would be an absolute bar, and Professor Crookes concluded that the conjectured ether must therefore be "*a very tenuous form of matter.*"

Mr. Snyder mentions that Professor Thomson has been at pains to shew that all incandescent bodies give off "corpuscles," and he continues, "The sun we conceive as incandescent. Is the sun therefore a gigantic cathode, negatively charged, sending off into space in every direction, myriads of millions of millions of these little carriers? So it appears. Some of these would strike the upper regions of the earth's atmosphere, and thus come under the influence of the earth's magnetism."*

The late Professor Clerk Maxwell, of Cambridge, was the first to suggest that what we call "waves" of light are not mechanical waves at all, but are immensely rapid electric displacements taking place in the all-pervading ether of space, accompanied, as all electric movements are, by magnetic forces in directions at right angles to the electric displacements. Dr. Silvanus P. Thompson, Principal and Professor of Physics in London Technical College, states that this theory is now in the main accepted by all the younger generation of physicists, and that in his opinion, it will be able, with proper modifications and developments, to explain the relations between

* *New Conceptions in Science*, p. 162.

electricity and the various properties of light. He goes on to say that this theory has led himself to the conclusion "that the ether, in which light is propagated, and which in all probability is the medium through which also all electric and magnetic forces are propagated when they act apparently 'at a distance,' is nothing else than *electricity* itself." *

Clerk Maxwell considered that electricity and light are, in essence, identical; and it was afterwards discovered that light and electricity are both ether waves, light being short waves, and electricity long ones. In order to support Clerk Maxwell's theory, the velocity of propagation of an electro-magnetic disturbance should equal the velocity of light. Professor J. J. Thomson mentions that a large number of experiments have been made with the view of ascertaining whether this is really the case; and he adds, "From these experiments, we conclude that the velocity of propagation of an electro-magnetic disturbance is equal to the velocity of light, and to the velocity required by Maxwell's theory." † The velocity of light,—and therefore the velocity of propagation of an electro-magnetic disturbance,—is nearly 186,000 miles per second.

Clerk Maxwell himself, in writing regarding the various suppositions as to the ether, mentions that the hypothesis of an ether has been maintained by different speculators for very different reasons; that

* *Electricity and Magnetism*, by A. Guillemin, edited by Silvanus P. Thompson, p. 372. † *Ency. Brit.*, 10th Ed., Vol. 28, p. 60.

ethers were invented for the planets to swim in; to constitute electric atmospheres and magnetic effluvia; to convey sensations from one part of our bodies to another, and so on, till all space had been filled three or four times over with ethers. He continues, "The only ether which has survived, is that which was invented by Huygens to explain the propagation of light. The evidence for the existence of the luminiferous ether has accumulated as additional phenomena of light and other radiations have been discovered, and the properties of this medium, as deduced from the phenomena of light, have been found to be precisely those required to explain electro-magnetic phenomena." *

There is thus the support of scientific opinion for believing that the space through which the earth moves in its orbital and diurnal revolutions is pervaded by a very tenuous medium of an electrical nature, and that currents or displacements of this medium are impelled with extreme rapidity from the very active centre of our system towards and upon the earth, and that these dash against the surface of the earth, or at least the enveloping atmosphere, and thus come under the influence of the earth's movements.

* *Ency. Brit.*, 10th Ed., Vol. 8, p. 569.

CHAPTER III.

The parts of the earth affected by the solar-electric waves.—The diurnal rotation and the electric waves the direct cause of the earth's magnetism.—The earth an electro-magnet.

WE have now seen that there is reason to believe that electric waves, or electric displacements in the surrounding ether, are occasioned by the activity of the sun, and impelled towards the earth with inconceivable rapidity. Let us now assume this to be the case, and consider how these waves are likely to come in contact with the earth, and what portions would be most exposed to their influence. If we accept the corpuscular theory of electricity, we can imagine the impact of these electrical streams as resembling a rain of minute particles, each particle being so small that a thousand of them would go to make up the smallest atom known to scientists. Whether this is so or not it is unnecessary for us to decide. We have merely to accept the hypothesis that, through the influence of the sun, certain electrical currents are set in motion and are impelled towards the earth and come in contact with it.

It is evident that only the half of the earth turned towards the sun will be actually exposed to the direct

force of these currents. The remaining half will be sheltered, except in so far as the part of the earth turned towards the direction of orbital progress comes in contact with the currents. This part of the earth will, we may suppose, cut through the currents at the speed of orbital progression, which is on the average about 18½ miles a second. Apparently the portion of the earth's surface, where it is mid-day, will be the portion most strongly exposed to these currents, as that portion, is, so to speak, in the direct line of fire. Probably, therefore, the electric "waves" will come in contact most strongly with each geographical meridian in turn about noon. Taking the meridian marking mid-day as the central line, we may suppose that during the six hours from 9 a.m. to 3 p.m., we pass through the period of greatest exposure to the electrical currents. The portion of the earth's surface, comprised between the meridian marking 9 a.m. and the meridian marking 3 p.m., is one-fourth. We have on one side of this space the district in which it is early morning, say between the meridians marking 6 a.m. and 9 a.m., and here, while the direct force of the currents will be less, as they must strike the earth at a greater angle than they strike the mid-day portion, the exposure to the currents is increased by both the orbital progression and the diurnal movement. On the other side we have the district in which it is early evening, between the meridians marking 3 p.m. and 6 p.m., where the reverse will be the case, the force of the currents being weakened, not only by the angle

of impact, but by both the orbital and diurnal motions.

While the stretch of the earth's surface most exposed to the direct force of these currents must be on, and in the neighbourhood of, the meridian marking mid-day, the boundary lines of the exposure will not be the equi-distant meridians marking 6 a.m. and 6 p.m., as the tilt of the earth's axis to the plane of its orbit —the obliquity of the ecliptic—will prevent this. The boundary lines of the direct impact of the currents will be the lines marking sunrise and sunset in the varying degrees of latitude. Similarly the direct force of the currents will not extend through the whole length of the meridian facing the sun at mid-day. The portion within the Arctic and Antarctic circles will, in the winters of these districts respectively, be sheltered from the exposure, and a corresponding portion of the opposite meridian will be included. Longitudinally, therefore, the direct impact of these currents will extend from a point on the Arctic circle in the north, to a diametrically opposite point on the Antarctic circle in the south. These two points may, in fact, be described as the "orbital poles," as they are the poles or apices of the earth as viewed from the plane of the orbit. These points will, of course, in the diurnal rotation, be caused to pass over every portion of the Arctic and Antarctic circles respectively, so that every portion of these circles will, once in every rotation, become what we have described as an orbital pole.

As we have spoken of orbital poles, we may also

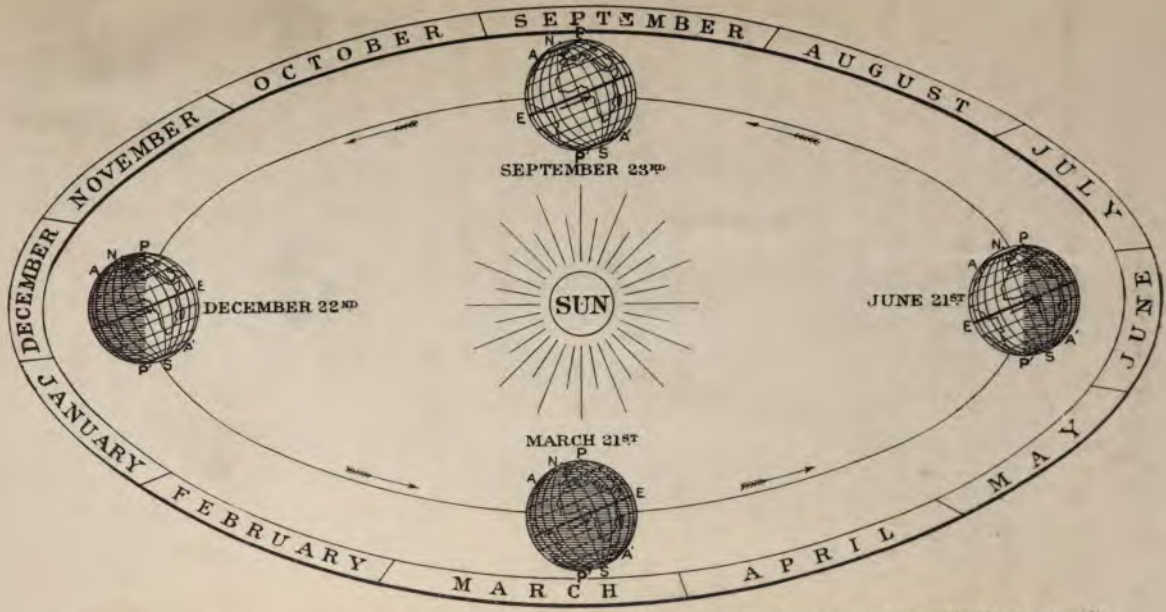

Diagram showing that the "orbital poles" are always on some portion of the Arctic and Antarctic Circles (p. 18). AP, A'P', Arctic and Antarctic Circles; P,P', Orbital poles; N,S., Geographical Poles; E., Geographical Equator.

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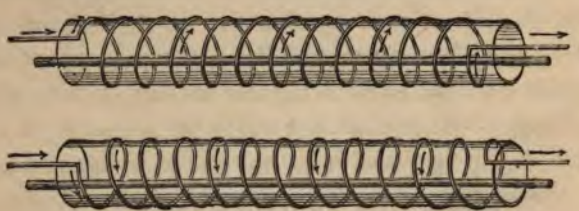
imagine a belt surrounding the earth on the plane of the orbit, and this belt will bear the same relation to the orbital poles as the geographical equator does to the geographical poles. As any point on the Arctic and Antarctic circles is about 23½ degrees distant from the corresponding geographical pole, so the "orbital equator," while it must of course intersect the geographical equator at two opposite points, will at the intermediate points, be, in one case, about 23½ degrees north, and, in the other case, about 23½ degrees south, of the geographical equator. It is evident that each point on this orbital equator will in its turn, at midday, be the place most directly exposed to the electric currents referred to, as being the central portion of the longitudinal stretch of the earth so exposed. Owing to the changing position of the earth in its orbit, and the practically unvarying obliquity of the ecliptic, the portion of the orbital equator so exposed will vary in relation to the geographical equator each succeeding day. This is of course the cause of the varying seasons. At the equinoxes, the point on the orbital equator which faces the sun at noon is one of the points *intersected* by the geographical equator, while at our midsummer it is a point about 23½° north, and at our midwinter a point about 23½ degrees south, of the geographical equator.

Let us now suppose that these electric currents come in contact with the earth, and its surrounding atmosphere in the way suggested. Then, as the earth rotates eastward, each portion of the earth in its turn

is brought under their influence. An electric sheet is thus wound around the earth from apex to apex in the course of the diurnal rotation. The direction of the apparent motion of this electrical sheet will be westwards on the earth's surface, this arising entirely from the diurnal movement being eastwards. The sheet may be compared to a great series of electric wires wound around the earth from east to west.

It is suggested that this would furnish a simple explanation of the magnetization of the earth.



Magnetization of a steel needle by right-handed and left-handed spiral coils.

In M. Guillemin's elaborate work on "Electricity and Magnetism," to which reference has already been made, it is stated that "the terrestrial globe is incessantly traversed by a multitude of electric currents generated by the chemical or other actions which take place within its mass. *All these currents*, with directions and strengths probably differing amongst one another and varying in amount and direction, *produce on magnets the same effect as a single resultant current circulating from east to west in a*

direction contrary to the movement of the rotation of the earth. *

It is suggested that the earth is really an electro-magnet, its magnetization being the result of these solar-induced electrical displacements in the ether. The mode of magnetization is thus similar to the method of magnetising a steel needle by sending an electric current through wires twisted around it.

We shall now turn our attention more particularly to the workings of terrestrial magnetism as revealed by the movements of the magnetic needle, and see whether they can be reconciled with the peculiarities connected with the magnetization of the earth in the way suggested, and whether the matters to which we have drawn attention in connection with the geographical bearings of the electric currents have any analagous points in the action of the magnetic needle.

* *Electricity and Magnetism*, p. 352.

CHAPTER IV.

The Elements of Terrestrial Magnetism.—The Diurnal, Seasonal, and Secular Variations in Declination and Dip.

LET us examine the bases of terrestrial magnetism in their geographical relations.

An imaginary circle, which is called the magnetic equator, surrounds the earth near the geographical equator, but the information regarding it is somewhat vague. Its position is, of course, judged merely from the action of the magnetic needle. In the maps relating to terrestrial magnetism, which have been prepared from the observations made by the late Sir F. Evans of the Royal Navy, the magnetic equator is shewn as an irregular circle which in two points intersects the geographical equator. M. Guillemin, on the other hand, distinctly states that the magnetic equator cuts the geographical equator in *four* points,* and he specifies the geographical position of two of these, one being in the Pacific Ocean, about 179 degrees east longitude, and the other being near St. Thomas' Isle off the west Coast of Africa, about 7 degrees or 8 degrees east longitude. The position of the two intersections, shewn in the map based on Sir F. Evans'

* *Electricity and Magnetism*, p. 82.

observations, is about 165 degrees west longitude, and about 5 degrees west longitude respectively. These positions are thus only about from 12 to 16 degrees distant from the two points specified by M. Guillemin, assuming that in both cases the meridian of Greenwich is reckoned from. If—as seems probable—M. Guillemin's statement refers to the distance from the meridian of Paris, this would alter his figures by about 2½ degrees, so that the point of intersection which he describes as being about 179 degrees east, in relation to Paris, would, in relation to Greenwich, be about 181½ degrees east—that is 178½ degrees west—being thus about 13½ degrees distant from the position shewn in the map referred to. Similarly, the point of intersection placed by M. Guillemin at 7 degrees or 8 degrees east in relation to Paris, would be about 9½ degrees or 10½ degrees east in relation to Greenwich, whereas the map referred to gives its position as about 5 degrees west, a difference of about 14½ or 15½ degrees. This discrepancy is not great, and it is very probable that the same points of intersection are referred to by both authorities, otherwise the difference would probably be much greater. The fact that such an authority as M. Guillemin distinctly asserts that the magnetic equator cuts the geographical equator in four points is disconcerting, seeing that he describes only two of these points, and that these points are, there is reason to believe, the two points of intersection shewn in the map based on Sir F. Evans' observations.

In M. Guillemin's volume, a small map is given in which the magnetic equator is shewn, and in it the magnetic equator appears to intersect the geographical equator in only two points, not four points as stated in the text, and the intersections appear to agree with the position of the two points of intersection, the geographical position of which is specified in the text.

The amount of discrepancy between these eminent authorities goes to shew the want of certainty which exists as to the exact geographical position of the magnetic equator. We may take it that it is known that the magnetic equator intersects the geographical equator at *two* points, at any rate, which are separated from each other by something like 160 degrees or 170 degrees of longitude, a distance rather less than one half of the circumference of the earth.

It is also known, that in other parts the magnetic equator is separated from the geographical equator by a varying distance, but, in regard to the distance of greatest separation, opinion also differs. Some authorities consider the extreme distance to be about 12 degrees, while others, more recently, give it as being about 15 degrees. Taking the degree of latitude as representing about 68 miles, this is a difference of about 204 miles. This goes to shew how difficult and uncertain observation in such a matter really is. If this, then, is the case in a portion of the earth so accessible as the equatorial regions, it is easy to conceive how much greater uncertainty is involved in

regard to magnetic observations in the more inaccessible regions.

The North Magnetic Pole was found by Sir James Clark Ross, in 1831, in 70° 5′ north, and 96° 43′ west; the locality being in Boothia in the extreme north of the Dominion of Canada. The South Magnetic Pole has never been actually discovered, but the same explorer calculated that its position is in 73° 30′ south latitude, and 147° 30′ east longitude. The North Magnetic Pole does not appear to have been actually visited by any scientist, since its discovery by Ross. A Norwegian expedition, however, left in 1903, for the express purpose of ascertaining its present geographical position, and the investigations may be continued till 1905.

In the observation of terrestrial magnetism there are three elements taken notice of in connection with the magnetic needle. The first is the *variation* of the needle from the true north. It is noticed whether the needle points east or west of the true north, and if so, the extent to which it deviates. The variation of the needle from the true north is called the declination, or sometimes simply the *variation*.

The second is the *dip* of the needle—or, as it is sometimes called, the inclination—and, as the word "dip" indicates, it refers to its deviation from the horizontal. At the magnetic equator there is no dip, the needle remaining perfectly horizontal, and, as we move towards the magnetic poles, the dip becomes apparent, and gradually increases, till, at the North Magnetic Pole, the end of the needle pointing northwards would dip 90°, that is to say,

straight downwards, the same being the case at the South Magnetic Pole with the opposite end of the needle. From this fact the magnetic poles are sometimes referred to as "the poles of verticity."

The remaining element, taken notice of in the observation of terrestrial magnetism, is the *intensity* or force of the magnetism, as shewn by the vibrations of the needle when diverted from its true direction.

We shall now consider the three elements, and more particularly those of declination and dip.

As regards declination,—it is found that there are daily variations, variations according to the seasons, and variations extending through long and uncertain periods. M. Guillemin quotes the following description of the needle's daily movements. "In the lower latitudes of the Northern Hemisphere the needle points nearest to the true north at a quarter past eight in the morning. From a quarter past eight in the morning to a quarter to two in the afternoon the needle moves from east to west, when it reaches its most westerly position. This movement to the west occurs all over the Northern Hemisphere whether the declination is westerly or easterly. From a quarter to two, when at its most westerly position, the needle retraces its steps towards the east during the evening and part of the night, until midnight or one o'clock in the morning. It often, however, makes a slight pause about six o'clock in the evening. During the night the needle again turns to the west very slightly, but

is at its most easterly position at a quarter past eight in the morning." *

As geographically the source of the needle's attraction is at present, in relation to Britain, west of the true north, and the declination of the needle westerly, the needle in this country points nearest to the true north at the time of the day when the westerly variation is smallest, which is, according to this authority, about 8.15 a.m. It will be noticed that according to the description quoted, the daily variation in declination corresponds with the time in the varying degrees of longitude. At Paris, the variation is most easterly when it is *in Paris* a quarter past eight in the morning, which is not the time at which it is a quarter past eight in the morning in London; while in London, the variation is most easterly at 8.15 a.m. in London, which is slightly later than the actual occurrence of the most easterly variation in Paris.

In regard to the seasons;—M. Guillemin says that "comparison of the monthly means has shewn in the northern stations that the needle moves to the west (that is to say the prevailing movement is westerly) from May to September; while it moves back from September to May; this is the inverse of what occurs in the Southern Hemisphere." † At Greenwich, the diurnal movement of the needle is about 12 minutes of the arc of the circle in summer, and only about 7 minutes in winter.

* *Electricity and Magnetism*, p. 70. † Do., p. 74.

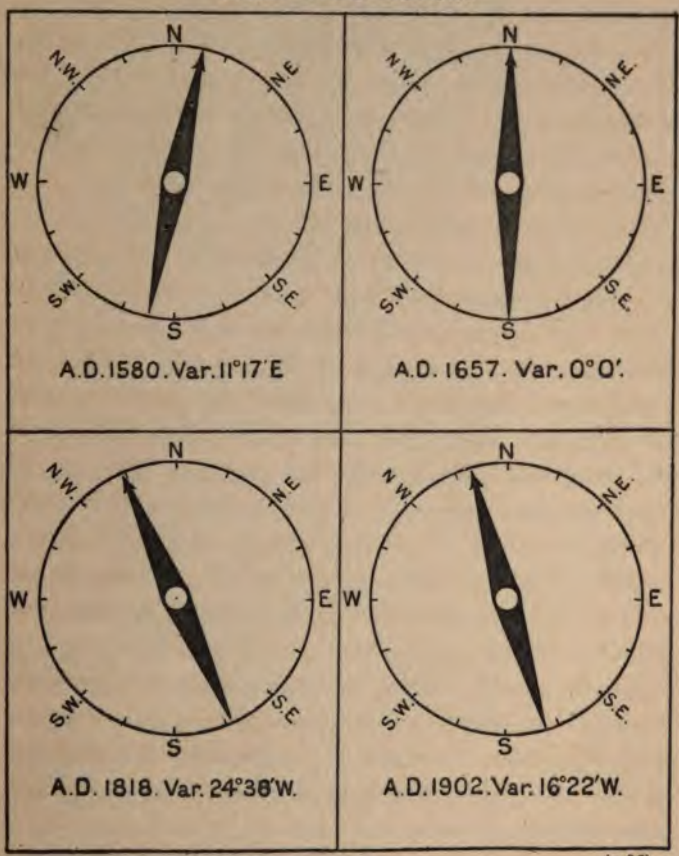
As regards the secular, or long-period variations, the needle in London, in the year 1580, pointed 11 degrees 17 minutes east of the true north. The variation from the true north slowly decreased till 1657, when the needle pointed to the true north. The variation then became westerly, till, in 1818, the needle pointed 24 degrees 38 minutes 25 seconds west of the true north. Ever since then, the westerly variation has been slowly diminishing, and it is now (1904) a little over 16 degrees.

The inclination or dip of the needle is also subject to long-period, seasonal, and daily variations. In Paris in 1671, the dip of the needle is said to have been 75 degrees. In 1754, it was 72 degrees 15 minutes, and since then it has continuously diminished, the dip in 1879—being the last date mentioned in M. Guillemin's work—having been 65 degrees 33 minutes. In London, or Kew, the dip is said to have been 74 degrees 42 minutes in 1723, which is the greatest dip recorded in England. Since then, it has very slowly and continuously diminished, having been only 67 degrees 3·4 minutes in 1902.

The intensity of the magnetic force may be said roughly to increase with the latitude, the minimum intensity being, it is stated, in the proximity of the equator, and the maximum in the proximity of the poles.

M. Guillemin asks the question whether the intensity of the magnetic force also varies from time to time. He considers that this is a very delicate question, and

Variation of the Magnetic Needle at London from True North.



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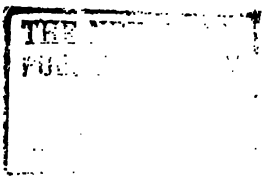
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one difficult to solve by observing the oscillations of a magnet, as no magnet will keep its strength unaltered for any length of time. He proceeds,—"Poisson described a method, which was afterwards perfected by Gauss, by means of which the absolute magnetic force can be measured without taking into account the strength of the magnets employed; the result of his observations, made at Göttingen, was negative. On the other hand Hansteen found both daily and monthly variations of the intensity, or at least of its horizontal component, which seem to be in agreement with the variations of dip. This result, however, does not prove any real change in the total absolute intensity. Lastly, the observations made at Kew and Greenwich have demonstrated the existence of a secular variation of this element."* It is now recognised that, like the declination and dip, the intensities of the horizontal and vertical forces also shew daily and secular changes. Of late years the horizontal force in Great Britain has been increasing every year by about one part in 600.

In the Appendix† there will be found a table giving the recorded variations in declination and dip in London and Paris for a long series of years, collected from various publications. There are many blanks in the series, but, from the dates for which the information is given, an approximation of the figures for the years omitted can be arrived at, so that it is possible approximately to base comparisons on the returns for these two places.

It may be mentioned, however, that even the average

* *Electricity and Magnetism*, p. 76. † See Appendix; No. I.

results are sometimes affected by the wide fluctuations occasioned by magnetic storms, and it is not improbable that the general progressive movement in declination and dip may occasionally appear in this way to be broken. This might be illustrated by the violent magnetic storm which occurred on 31st October 1903 in the course of which the range of the compass needle at Kew was about $2\frac{1}{4}$ degrees. Several times during the day the needle moved over a degree in the course of a few minutes. But, of course, such wide fluctuations as these are now disregarded in tables illustrative of the mean movement.

M. Guillemin mentions in his treatise that the extent of the daily variation in declination depends on the latitude. In high latitudes it is as great as 15 minutes, whilst near the magnetic equator it is only 3 minutes or 4 minutes. In Great Britain, and also in Paris, it is on the average about 10 minutes, but the range of the daily motion is considerably greater at midsummer than it is at midwinter. These variations occur in the Southern Hemisphere just as in the Northern Hemisphere, but the movements are reversed. When the end of the needle indicating the north moves westerly in the Northern Hemisphere, it is the end of the needle indicating the south which moves westerly in the Southern Hemisphere, and the like is the case for the other movements

CHAPTER V.

Similarities of the "Orbital Equator" and the Magnetic Equator, and of the "Orbital Poles" and the Magnetic Poles.—A distinction between the "Orbital Poles" and the Magnetic Poles.—An Explanation of the distinction.

We have now seen that the magnetic equator like the orbital equator is known to intersect the geographical equator in two points. According to one authority, indeed, it intersects the geographical equator in four points. We need not contradict this statement which does not at present concern us. As to whether the magnetic equator does or does not intersect the geographical equator in *more* than two points, opinion may differ, but all authorities are agreed that it, at any rate, does intersect the geographical equator in two points. In this important respect, therefore, there can be no doubt as to the similiarity of the magnetic equator and the orbital equator. Both are belts around the earth in the neighbourhood of the geographical equator, and both intersect the geographical equator in two points. Both also are in other parts separated from the geographical equator by a varying distance. The extreme distance of separation in the case of the orbital equator will, as we have seen, be about 23½ degrees. As to the extreme distance

of separation in the case of the magnetic equator, opinion differs, some authorities, as already mentioned, considering it to be about 12 degrees, while other, and more recent, authorities give the distance as 15 degrees. Thus the orbital and magnetic equators resemble each other in respect that each is situated in the equatorial regions; each doubly intersects the geographical equator; and each is in other parts at a varying distance from it. If the magnetic equator intersects the geographical equator in more than two points, this would constitute a difference between it and the orbital equator, and if the extreme distance of separation between the magnetic equator and the geographical equator is 15 degrees, this also would constitute a difference between the magnetic equator and the orbital equator. As to both these matters, however, authorities differ, while in regard to the points of resemblance there is no difference of opinion.

We have found that the orbital poles are situated geographically at a distance of about 23½ degrees from the poles of the earth's axis, their position being therefore in, or in the neighbourhood of, latitude 66° 33′, and we have seen that the North Magnetic Pole was found by Sir James Clark Ross in 1831, at latitude 70° 5′ north, a latitudinal distance of only 3° 32′ from the conjectured position in latitude of the North Orbital Pole. The South Magnetic Pole has not yet been actually found,* and its position is thus

* The position of this pole will doubtless be more accurately determined, from observations made by the *Discovery* in 1903. See note at end of Chap. XVII.

merely a matter of calculation. Its supposed latitude is 73° 30′ south, a distance of about 7 degrees from the conjectured latitude of the South Orbital Pole.

These resemblances between the orbital and magnetic equators and poles, are sufficiently striking to suggest to any inquiring mind that there may be a natural relation between them; that the magnetic equator probably has some natural relation to the orbital equator, and that the magnetic poles probably have some natural relation to the points which form the apices of the earth, as viewed from the plane of the orbit.

If we now in this connection think over the theory we have ventured to suggest as explanatory of the existence of terrestrial magnetism, we shall find that the theory seems at first to point towards there being not only a close relation between the orbital and magnetic equators, and between the orbital and magnetic poles, but even towards identity. It seems to indicate that the orbital equator must really be the magnetic equator, that the orbital poles must really be the magnetic poles. For, if the earth is magnetised by the impact of a stream of electrical waves originated by the sun, as we have supposed,—a stream which, in relation to the earth, will resemble a sheet of electrical influence stretching from apex to apex of the earth on the side turned towards the sun,—is it not to be expected, from what occurs in ordinary magnetization, that the magnetic equator will be formed at, or nearly at, the centre of this stream? Is it not to be expected that the magnetic poles will be formed at the apices?

straight downwards, the same being the case at the South Magnetic Pole with the opposite end of the needle. From this fact the magnetic poles are sometimes referred to as "the poles of verticity."

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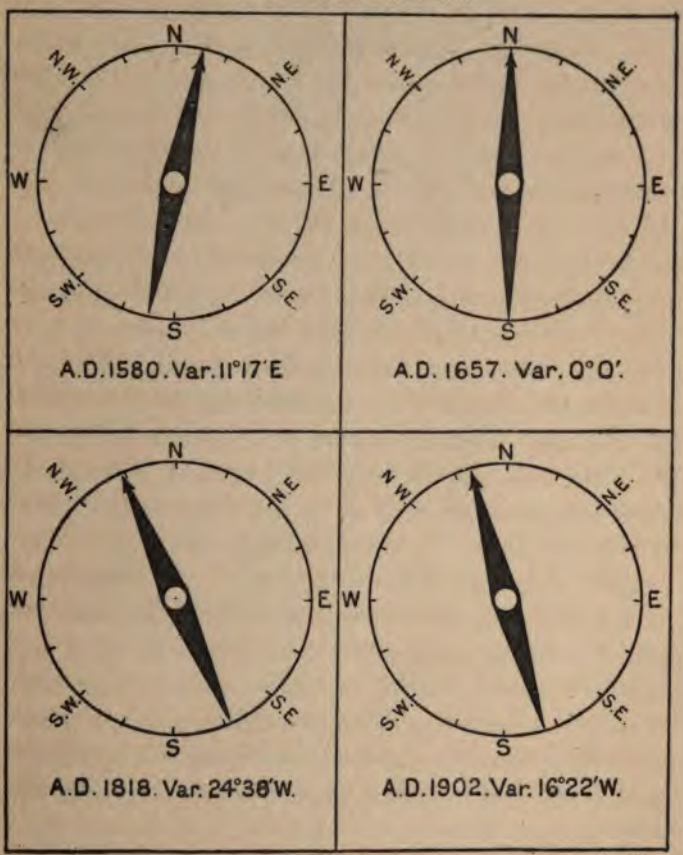

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CHAPTER VI.

The peculiarities in the conjectured method of the Earth's magnetization compared with the peculiarities in the resulting magnetism, as shown by the daily movements of the magnetic needle—The daily changes of the magnetic needle in declination and dip, at Kew—Comparison of the changes in declination in different latitudes—An explanation of the difference in the daily movements of the magnetic needle in different localities.

We have noticed in a former chapter the peculiarities which exist, through the conjectured method of the earth's magnetization, in regard to the geographical impact of the supposed electric currents. We shall now enquire whether, as we should expect to be the case if the theory propounded has any foundation in fact, any analagous peculiarities are revealed in the earth's magnetism by the actions of the magnetic needle.

We have seen that each meridian is in turn brought daily under the influence of these currents, excepting only the portion within the Arctic and Antarctic circles in the winters of these regions respectively. As the excepted portion is not of special importance in connection with our present enquiry, we may leave it out of account. Thus we may regard each meridian as in turn coming under the influence of the electrical waves which flow from the sun. The influence of these will therefore gradually

one difficult to solve by observing the oscillations of a magnet, as no magnet will keep its strength unaltered for any length of time. He proceeds,—"Poisson described a method, which was afterwards perfected by Gauss, by means of which the absolute magnetic force can be measured without taking into account the strength of the magnets employed; the result of his observations, made at Göttingen, was negative. On the other hand Hansteen found both daily and monthly variations of the intensity, or at least of its horizontal component, which seem to be in agreement with the variations of dip. This result, however, does not prove any real change in the total absolute intensity. Lastly, the observations made at Kew and Greenwich have demonstrated the existence of a secular variation of this element."* It is now recognised that, like the declination and dip, the intensities of the horizontal and vertical forces also shew daily and secular changes. Of late years the horizontal force in Great Britain has been increasing every year by about one part in 600.

In the Appendix† there will be found a table giving the recorded variations in declination and dip in London and Paris for a long series of years, collected from various publications. There are many blanks in the series, but, from the dates for which the information is given, an approximation of the figures for the years omitted can be arrived at, so that it is possible approximately to base comparisons on the returns for these two places.

It may be mentioned, however, that even the average

* *Electricity and Magnetism*, p. 76. † See Appendix; No. I.

results are sometimes affected by the wide fluctuations occasioned by magnetic storms, and it is not improbable that the general progressive movement in declination and dip may occasionally appear in this way to be broken. This might be illustrated by the violent magnetic storm which occurred on 31st October 1903 in the course of which the range of the compass needle at Kew was about $2\frac{1}{4}$ degrees. Several times during the day the needle moved over a degree in the course of a few minutes. But, of course, such wide fluctuations as these are now disregarded in tables illustrative of the mean movement.

M. Guillemin mentions in his treatise that the extent of the daily variation in declination depends on the latitude. In high latitudes it is as great as 15 minutes, whilst near the magnetic equator it is only 3 minutes or 4 minutes. In Great Britain, and also in Paris, it is on the average about 10 minutes, but the range of the daily motion is considerably greater at midsummer than it is at midwinter. These variations occur in the Southern Hemisphere just as in the Northern Hemisphere, but the movements are reversed. When the end of the needle indicating the north moves westerly in the Northern Hemisphere, it is the end of the needle indicating the south which moves westerly in the Southern Hemisphere, and the like is the case for the other movements

CHAPTER V.

Similarities of the "Orbital Equator" and the Magnetic Equator, and of the "Orbital Poles" and the Magnetic Poles.—A distinction between the "Orbital Poles" and the Magnetic Poles.—An Explanation of the distinction.

We have now seen that the magnetic equator like the orbital equator is known to intersect the geographical equator in two points. According to one authority, indeed, it intersects the geographical equator in four points. We need not contradict this statement which does not at present concern us. As to whether the magnetic equator does or does not intersect the geographical equator in *more* than two points, opinion may differ, but all authorities are agreed that it, at any rate, does intersect the geographical equator in two points. In this important respect, therefore, there can be no doubt as to the similiarity of the magnetic equator and the orbital equator. Both are belts around the earth in the neighbourhood of the geographical equator, and both intersect the geographical equator in two points. Both also are in other parts separated from the geographical equator by a varying distance. The extreme distance of separation in the case of the orbital equator will, as we have seen, be about 23½ degrees. As to the extreme distance

of separation in the case of the magnetic equator, opinion differs, some authorities, as already mentioned, considering it to be about 12 degrees, while other, and more recent, authorities give the distance as 15 degrees. Thus the orbital and magnetic equators resemble each other in respect that each is situated in the equatorial regions; each doubly intersects the geographical equator; and each is in other parts at a varying distance from it. If the magnetic equator intersects the geographical equator in more than two points, this would constitute a difference between it and the orbital equator, and if the extreme distance of separation between the magnetic equator and the geographical equator is 15 degrees, this also would constitute a difference between the magnetic equator and the orbital equator. As to both these matters, however, authorities differ, while in regard to the points of resemblance there is no difference of opinion.

We have found that the orbital poles are situated geographically at a distance of about 23½ degrees from the poles of the earth's axis, their position being therefore in, or in the neighbourhood of, latitude 66° 33′, and we have seen that the North Magnetic Pole was found by Sir James Clark Ross in 1831, at latitude 70° 5′ north, a latitudinal distance of only 3° 32′ from the conjectured position in latitude of the North Orbital Pole. The South Magnetic Pole has not yet been actually found,* and its position is thus

* The position of this pole will doubtless be more accurately determined, from observations made by the *Discovery* in 1903. See note at end of Chap. XVII.

merely a matter of calculation. Its supposed latitude is 73° 30′ south, a distance of about 7 degrees from the conjectured latitude of the South Orbital Pole.

These resemblances between the orbital and magnetic equators and poles, are sufficiently striking to suggest to any inquiring mind that there may be a natural relation between them; that the magnetic equator probably has some natural relation to the orbital equator, and that the magnetic poles probably have some natural relation to the points which form the apices of the earth, as viewed from the plane of the orbit.

If we now in this connection think over the theory we have ventured to suggest as explanatory of the existence of terrestrial magnetism, we shall find that the theory seems at first to point towards there being not only a close relation between the orbital and magnetic equators, and between the orbital and magnetic poles, but even towards identity. It seems to indicate that the orbital equator must really be the magnetic equator, that the orbital poles must really be the magnetic poles. For, if the earth is magnetised by the impact of a stream of electrical waves originated by the sun, as we have supposed,—a stream which, in relation to the earth, will resemble a sheet of electrical influence stretching from apex to apex of the earth on the side turned towards the sun,—is it not to be expected, from what occurs in ordinary magnetization, that the magnetic equator will be formed at, or nearly at, the centre of this stream? Is it not to be expected that the magnetic poles will be formed at the apices?

straight downwards, the same being the case at the South Magnetic Pole with the opposite end of the needle. From this fact the magnetic poles are sometimes referred to as "the poles of verticity."

The remaining element, taken notice of in the observation of terrestrial magnetism, is the *intensity* or force of the magnetism, as shewn by the vibrations of the needle when diverted from its true direction.

We shall now consider the three elements, and more particularly those of declination and dip.

As regards declination,—it is found that there are daily variations, variations according to the seasons, and variations extending through long and uncertain periods. M. Guillemin quotes the following description of the needle's daily movements. "In the lower latitudes of the Northern Hemisphere the needle points nearest to the true north at a quarter past eight in the morning. From a quarter past eight in the morning to a quarter to two in the afternoon the needle moves from east to west, when it reaches its most westerly position. This movement to the west occurs all over the Northern Hemisphere whether the declination is westerly or easterly. From a quarter to two, when at its most westerly position, the needle retraces its steps towards the east during the evening and part of the night, until midnight or one o'clock in the morning. It often, however, makes a slight pause about six o'clock in the evening. During the night the needle again turns to the west very slightly, but

is at its most easterly position at a quarter past eight in the morning." *

As geographically the source of the needle's attraction is at present, in relation to Britain, west of the true north, and the declination of the needle westerly, the needle in this country points nearest to the true north at the time of the day when the westerly variation is smallest, which is, according to this authority, about 8.15 a.m. It will be noticed that according to the description quoted, the daily variation in declination corresponds with the time in the varying degrees of longitude. At Paris, the variation is most easterly when it is *in Paris* a quarter past eight in the morning, which is not the time at which it is a quarter past eight in the morning in London; while in London, the variation is most easterly at 8.15 a.m. in London, which is slightly later than the actual occurrence of the most easterly variation in Paris.

In regard to the seasons;—M. Guillemin says that "comparison of the monthly means has shewn in the northern stations that the needle moves to the west (that is to say the prevailing movement is westerly) from May to September; while it moves back from September to May; this is the inverse of what occurs in the Southern Hemisphere." † At Greenwich, the diurnal movement of the needle is about 12 minutes of the arc of the circle in summer, and only about 7 minutes in winter.

* *Electricity and Magnetism*, p. 70. † Do., p. 74.

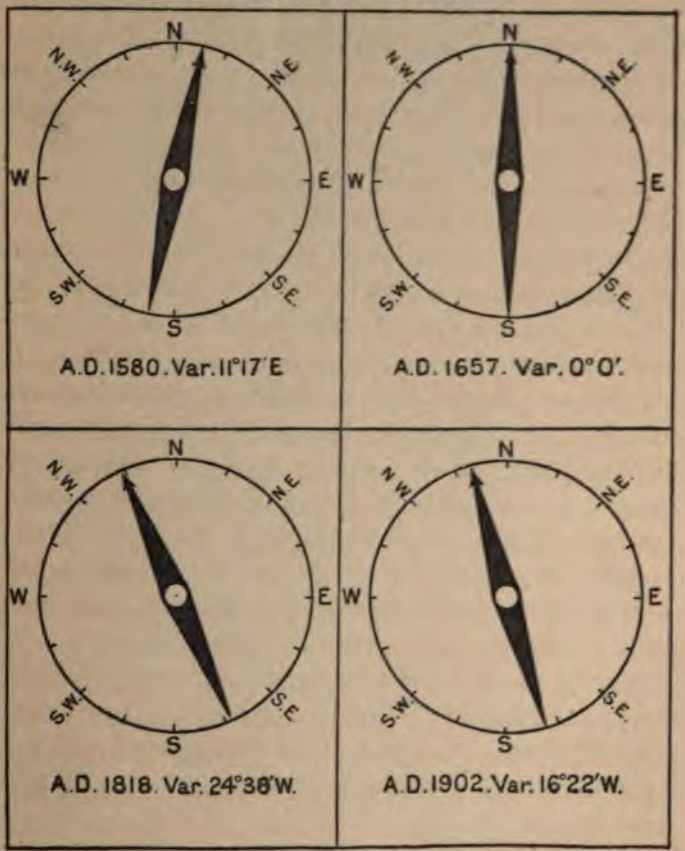
As regards the secular, or long-period variations, the needle in London, in the year 1580, pointed 11 degrees 17 minutes east of the true north. The variation from the true north slowly decreased till 1657, when the needle pointed to the true north. The variation then became westerly, till, in 1818, the needle pointed 24 degrees 38 minutes 25 seconds west of the true north. Ever since then, the westerly variation has been slowly diminishing, and it is now (1904) a little over 16 degrees.

The inclination or dip of the needle is also subject to long-period, seasonal, and daily variations. In Paris in 1671, the dip of the needle is said to have been 75 degrees. In 1754, it was 72 degrees 15 minutes, and since then it has continuously diminished, the dip in 1879—being the last date mentioned in M. Guillemin's work—having been 65 degrees 33 minutes. In London, or Kew, the dip is said to have been 74 degrees 42 minutes in 1723, which is the greatest dip recorded in England. Since then, it has very slowly and continuously diminished, having been only 67 degrees 3·4 minutes in 1902.

The intensity of the magnetic force may be said roughly to increase with the latitude, the minimum intensity being, it is stated, in the proximity of the equator, and the maximum in the proximity of the poles.

M. Guillemin asks the question whether the intensity of the magnetic force also varies from time to time. He considers that this is a very delicate question, and

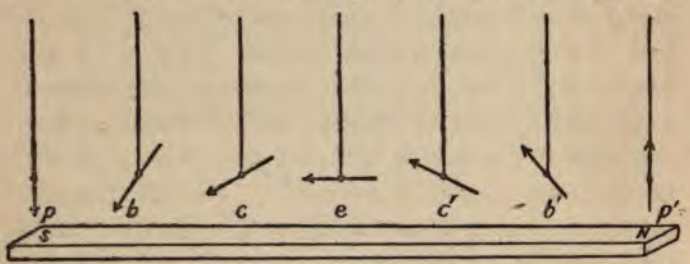
Variation of the Magnetic Needle at London from True North.



(p 24)

pole from the place of observation. Indeed, this appears necessarily to follow from the fact that at the magnetic equator there is no dip, and that the dip gradually increases as we move from the magnetic equator towards the magnetic pole, as in the case of a needle suspended above a magnetic bar.

One difficulty arises in connection with the Table of hourly variations in declination. The speed of the earth in its diurnal rotation does not vary during the different hours of the day. Now we have supposed



DIP OF THE NEEDLE ON A MAGNETIC BAR.

e Magnetic "equator," no dip: b,b'; c,c', dip increasing as poles of magnet are approached: p,p' magnetic poles, 90° dip.

the daily rotatory displacement of the magnetic pole to be caused by the earth's rotation. If this is so, then the circular progress of the pole should be constant during each hour of the day. But this does not appear to be in accordance with the Tables of hourly variation. Then again, if the needle at Kew is tracing the movement of the pole during the large changes in variation occurring in the early hours of the afternoon, and thus revealing a great movement of the pole during these hours, such movement must

one difficult to solve by observing the oscillations of a magnet, as no magnet will keep its strength unaltered for any length of time. He proceeds,—"Poisson described a method, which was afterwards perfected by Gauss, by means of which the absolute magnetic force can be measured without taking into account the strength of the magnets employed; the result of his observations, made at Göttingen, was negative. On the other hand Hansteen found both daily and monthly variations of the intensity, or at least of its horizontal component, which seem to be in agreement with the variations of dip. This result, however, does not prove any real change in the total absolute intensity. Lastly, the observations made at Kew and Greenwich have demonstrated the existence of a secular variation of this element."* It is now recognised that, like the declination and dip, the intensities of the horizontal and vertical forces also shew daily and secular changes. Of late years the horizontal force in Great Britain has been increasing every year by about one part in 600.

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It may be mentioned, however, that even the average

* *Electricity and Magnetism*, p. 76. † See Appendix; No. I.

results are sometimes affected by the wide fluctuations occasioned by magnetic storms, and it is not improbable that the general progressive movement in declination and dip may occasionally appear in this way to be broken. This might be illustrated by the violent magnetic storm which occurred on 31st October 1903 in the course of which the range of the compass needle at Kew was about $2\frac{1}{4}$ degrees. Several times during the day the needle moved over a degree in the course of a few minutes. But, of course, such wide fluctuations as these are now disregarded in tables illustrative of the mean movement.

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CHAPTER V.

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as the rotation continues, we again come under the direct influence of the solar waves, and in due time the needle once again, as the source of its attraction is, so to speak, drawn above the horizon, resumes its daily westward course.

It has been suggested above that the movement of the magnetic pole geographically may be merely a swinging movement of slight extent. With reference to the *sun*—the suggested source of the earth's magnetism—the magnetic poles do undoubtedly execute a swinging movement. The North Magnetic Pole, for instance, is nearly 1400 miles from the Geographical Pole, hence its daily circuit round that pole is a circle having a diameter of about 2800 miles. In the time, however, occupied by the pole in travelling over the circumference of this circle, the earth has moved about 1,600,000 miles forward in its orbit, and as the combined result of the two motions, the North Magnetic Pole traces out a wavy course with reference to the sun, receding from the sun from noon (at the longitude of the magnetic pole) till midnight, and approaching it from midnight till noon. But being only in the ratio of about 2800 to 1,600,000, or 1-570th, this motion of recession and approach is, in comparison with the daily forward movement, of small extent.

We shall, later on (Chap. XV. and XVI.), consider more particularly the conjectured daily movement of the North Magnetic Pole or its centre of primary attraction, in connection with the movements of the needle at various stations in the Northern Hemisphere.

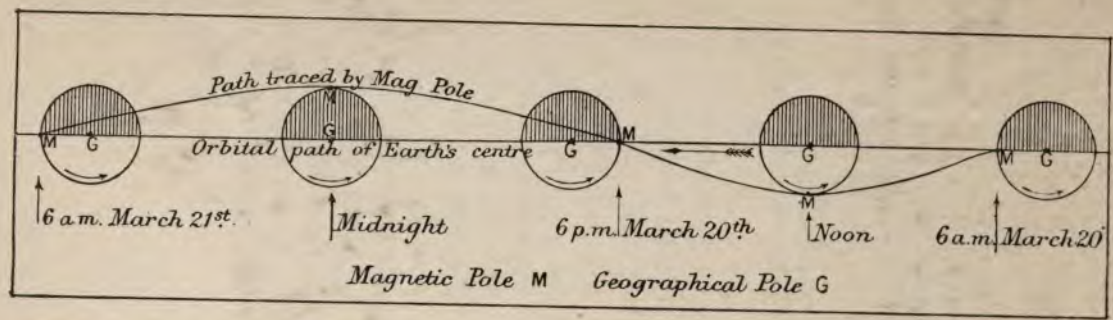

Diagram showing the daily swaying motion of the magnetic poles towards and away from the sun (p. 52).

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CHAPTER VII.

The Seasonal Variations in Declination and Dip considered in connection with the Theory of Terrestrial Magnetism being induced by solar-projected Electric Currents.

We have already noticed that if the earth's magnetism is produced by the projection from the sun of electrical displacements in the ether, the effect on the different portions of the earth's surface will vary according to the exposure to the sun. As the variation of the exposure of the surface to the sun is also the cause of the varying seasons, it follows that the exposure of each hemisphere to the electric currents will vary according to the seasons.

The fact that terrestrial magnetism is also, as indicated by the actions of the magnetic needle, subject to seasonal variations, has been previously mentioned. We have now to consider these seasonal variations of the magnetic needle more carefully, and to enquire whether they are such as might be looked for from the seasonal changes of what we have conjectured to be the inducing cause of the earth's magnetism, or at least whether they are in conformity with the theory submitted.

It will be seen from the tables given in the pre-

ceding chapter that there is a great difference in the range of the daily variation of declination between the summer months and the winter months. In the months from April to September, it appears that at Kew (Latitude 51° 28′) the average daily movement westward is 33·94 minutes, and the average daily movement eastward 33·92 minutes, making the total average daily movement 67·86 minutes. In the months from October to March, the corresponding figures are 22·74 minutes westward, and 22·76 minutes eastward, making the total daily movement 45·5 minutes, or just about two-thirds of the summer daily movement.

At the equatorial station of Trivandrum (Latitude 8° 22′ N.), the seasonal difference is even greater, although the movement is complicated by the fact that in the summer months it is not continuous in each direction, there being a westward movement from noon till about 4 p.m.; then a slight eastward movement for about three hours, the westward movement recommencing about 7 p.m., and continuing till about midnight, when the movement again becomes easterly and so continues till about 11 o'clock in the forenoon. In the months from October to March, the movement is free from this complication, being continuously eastward from noon till about 3 a.m., and continuously westward for the remainder of the twenty-four hours. The total daily eastward movement in the months from April to September is 6 minutes, and the westward movement is the same, making the range of variation 12 minutes. From

October to March, the eastward and westward variations are each on the daily average only 3·62 minutes, making the range of variation 7·24 minutes, which is considerably less than two-thirds of the summer range. Trivandrum is in the extreme south of India, in about latitude 8° 22′ north, and longitude 77 degrees east.

As these observations relate to a station in the middle latitude of the Northern Hemisphere, and a station in equatorial latitude respectively, we may also note the results recorded at a station in the middle latitude of the Southern Hemisphere. These results are given in the Encyclopædia Britannica,* the station being Hobart, in Tasmania; which is situated in latitude 42° 52·5′ south, and longitude 147° 27·5′ east. The results are as given in the table on the next page.

It is evident at a glance that the greater variation takes place in the opposite months from those in which it occurs at Kew and Trivandrum, but as this happens in the Southern Hemisphere, the greater variation is still in the summer months. As in Kew, we have at Hobart a continuous movement in each direction, there being no intervening displacement in the opposite direction, such as occurs in the summer months at Trivandrum. At Hobart the daily easterly variation in the months from April to September is on the average 13·60 minutes, and the westerly variation is the same, making the range of variation 27·20

* 9th Edition, XVI., p. 168.

CHANGE OF DECLINATION OF MAGNETIC NEEDLE AT HOBART AND KEW.

Astronomical Hours.	*AVERAGE HOURLY CHANGE.*					
	April to September.		*October to March.*		*Whole Year.*	
	Hobart.	*Kew.*	*Hobart.*	*Kew.*	*Hobart.*	*Kew.*
0- 1	0·35′ E.	6·15′ W.	2·35′ E.	4·12′ W.	1·35′ E.	5·13′ W.
1- 2	2·15′ „	7·42′ „	4·85′ „	4·96′ „	3·50′ „	6·19′ „
2- 3	3·15′ „	6·94′ „	5·95′ „	4·67′ „	4·55′ „	5·81′ „
3- 4	3·30′ „	5·21′ „	5·50′ „	3·35′ „	4·40′ „	4·28′ „
4- 5	2·40′ „	3·25′ „	4·30′ „	1·95′ „	3·35′ „	2·60′ „
5- 6	1·30′ „	1·47′ „	2·70′ „	1·05′ „	2·00′ „	1·26′ „
6- 7	0·75′ „	0·32′ „	1·55′ „	0·46′ „	1·15′ „	0·39′ „
7- 8	0·20′ „	0·22′ E.	0·80′ „	0·21′ E.	0·50′ „	0·22′ E.
8- 9	0·30′ W.	0·44′ „	0·30′ „	0·92′ „	0·00′ „	0·68′ „
9-10	0·85′ „	0·52′ „	0·25′ W.	1·45′ „	0·55′ W.	0·99′ „
10-11	1·10′ „	0·70′ „	0·70′ „	1·77′ „	0·90′ „	1·24′ „
11-12	1·15′ „	0·90′ „	0·85′ „	1·84′ „	1·00′ „	1·37′ „
12-13	1·10′ „	1·19′ „	0·80′ „	1·67′ „	0·95′ „	1·43′ „
13-14	0·75′ „	1·23′ „	0·75′ „	1·34′ „	0·75′ „	1·29′ „
14-15	0·40′ „	1·56′ „	0·70′ „	1·22′ „	0·55′ „	1·39′ „
15-16	0·15′ „	1·93′ „	0·65′ „	1·09′ „	0·40′ „	1·51′ „
16-17	0·02′ „	2·58′ „	0·78′ „	1·17′ „	0·40′ „	1·88′ „
17-18	0·10′ „	3·60′ „	1·40′ „	1·43′ „	0·75′ „	2·51′ „
18-19	0·23′ „	4·59′ „	2·37′ „	1·54′ „	1·30′ „	3·07′ „
19-20	0·50′ „	5·31′ „	3·80′ „	1·85′ „	2·15′ „	3·58′ „
20-21	1·25′ „	5·20′ „	5·25′ „	2·40′ „	3·25′ „	3·80′ „
21-22	2·10′ „	3·57′ „	5·30′ „	2·32′ „	3·70′ „	2·95′ „
22-23	2·20′ „	0·38′ „	3·80′ „	0·54′ „	3·00′ „	0·46′ „
23- 0	1·40′ „	3·18′ W.	0·80′ „	2·18′ W.	1·15′ „	2·68′ W.

minutes. From October to March the easterly variation is 28·30 minutes, and the westerly variation 28·20 minutes, making the daily range of variation 56·50 minutes, or more than double what it is from April to September.

In both the Northern and Southern Hemispheres, the end of the needle indicating the north is the end observed in recording the variation, so that the motion of the needle in the Southern Hemisphere is in the opposite direction to that in which it moves in the Northern Hemisphere at the same time.

Dr. Charles Chree in an article on terrestrial magnetism in the new edition of the Encyclopædia Britannica says, that "generally speaking there is a distinct minimum amplitude in December in the Northern, and in June in the Southern Hemisphere," as is indeed shewn by the tables we have given.

Unfortunately, similar tables shewing the seasonal variations in dip are not available. M. Guillemin, however, states that the value of the dip has been determined in the middle latitudes of the Northern Hemisphere, from a large number of observations, to be 15 minutes greater in summer than in winter.*

These seasonal changes in the action of the magnetic needle are thus exactly similar to the changes in the exposure to the electric currents. The greater the exposure, the greater is the movement of the needle. As the exposure to the electric currents is lessened, the activity of the needle decreases.

* *Electricity and Magnetism*, p. 75.

May we then assume that this indicates an actual difference in the extent of the daily movement of the magnetic pole in the summer and winter months respectively? Is it possible that the magnetic pole, or the centre of primary influence in the magnetic pole, travels along the circumference of a larger daily circuit in the summer months than it does in the winter months? Supposing this to be so, the daily movement at the North and South Magnetic Poles would be of similar extent only at the equinoxes, when the exposure of the Northern and Southern Hemispheres to the electric influence is equal. During our summer, the movement of the North Magnetic Pole would be much larger than the movement of the South Magnetic Pole, and the converse would be the case in our winter. But if the displacement of the pole is a result of the earth's daily rotation, it seems improbable that this can be the case. The earth's rotatory movement affects the Southern Hemisphere just the same in our summer as in our winter. Any change in the earth's rotation would of course effect both Hemispheres equally. It is difficult, therefore, to imagine that the actual displacement of the magnetic poles changes materially with the changes of season, and to account for the large difference in the range of declination, a material change would have to be looked for.

Is it not more likely that, with less direct exposure to the electric influences, the strength of the magnetization of the locality is lessened, and that the action of the magnetic needle is therefore more sluggish;

that although the displacement of the magnetic pole is of the same extent, the pole itself,—being for a time shielded altogether from the direct influence of the sun—is of weaker attraction, and the magnetic needle does not, therefore, so readily respond to its influence.

In summer, in each Hemisphere in turn, owing to the more direct exposure to the electrical influence of the sun, the magnetization will be more powerful than in winter, and the attractive force of the magnetic pole stronger, while in winter, in each Hemisphere in turn, the opposite will be the case. This furnishes a more reasonable explanation of the difference in the amplitude of the daily movement of the magnetic needle in these seasons, than to suppose an actual and material difference in the extent of the daily displacement of the magnetic pole.

Such an explanation would agree with the theory of the earth being an electro-magnet, with the producing causes of its magnetization subject to seasonal change.

It is probable that the seasonal changes are also influenced by the varying distance of the earth from the sun. In the beginning of January, the earth is at its nearest distance to the sun, the distance being then about 91,336,000 miles; while, at the beginning of July, the distance between the earth and the sun is greatest, being about 94,458,000 miles, a difference of more than three millions of miles. Now, the orbital speed of the earth varies inversely according to its distance from the sun, being greatest when the earth is nearest to the sun, and least when it is farthest away.

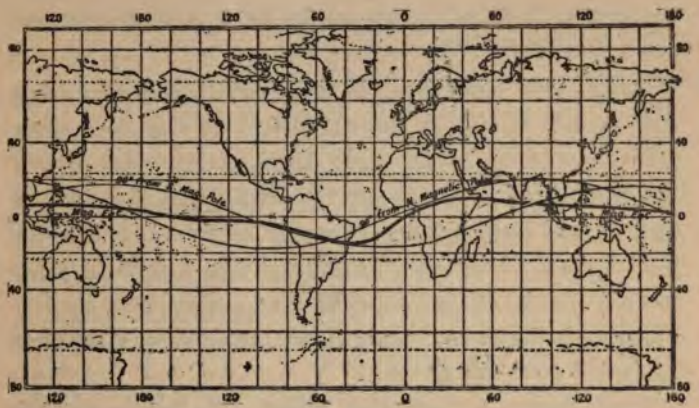
It would appear to follow, that, in the beginning of January, the force of impact of the electrical currents, projected outwards from the sun, will be greatest, and, in the beginning of July, least. On the other hand, at the former season, the earth will pass through the currents at a greater speed than at the latter season. If, then, the intensity of the earth's magnetism varies directly according to the *force* of these currents, it would appear that the magnetic intensity of the earth as a whole, must be greatest in the beginning of January, and least in the beginning of July.

In the Northern Hemisphere, however, the nearest approach of the earth to the sun occurs during the winter season, when that hemisphere is least exposed to the sun; so that the greatest force of impact of the currents coincides with the time of least superficial exposure to them, and thus one set of circumstances may counteract the other. In the Southern Hemisphere, the opposite is the case, the greatest force of impact occurring at the time of greatest exposure to the currents.

Thus these causes will differently affect the two hemispheres, and will probably produce differences in the relative magnetic intensity.

The seasonal changes of intensity in the northern and southern hemispheres, will probably afford an explanation of M. Guillemin's statement that the magnetic equator intersects the geographical equator in four points, of which he only specifies two. It will be seen by reference to the map, that the magnetic equator approaches very closely to the geographical one, between longitudes

105° and 135° W., hence, as the intensity in each hemisphere waxes and wanes, the magnetic equator will move slightly to the north or south, and thus, perhaps, at certain seasons of the year, cause the two additional intersections.



The Magnetic Equator, according to Evans: also the position of circles 90° from the North and South Magnetic Poles.

CHAPTER VIII.

The argument for the existence of a magnetic pole in Northern Asia as well as in North America.

HALLEY, the distinguished mathematician, who was Astronomer Royal in the early part of the eighteenth century, was led to conclude, from his observations of the declination of the magnetic needle, that the earth is distinctly different from ordinary magnets in respect that it must be regarded as having two magnetic poles in the northern hemisphere, and other two in the southern hemisphere. The earth he believed had four magnetic poles altogether.

The process of reasoning which led Halley to this conclusion is explained by Dr. Balfour Stewart in his article on Terrestrial Magnetism in the ninth edition of the Encyclopædia Britannica. He asks us to imagine,

"That the earth has only a single pole or force-focus in the northern hemisphere, and that this is coincident with its geographical pole, then, assuming that this pole has a causative influence on the needle's declination, we should expect all needles to point everywhere due north. If, however, this pole be not coincident with the north pole of the earth, let us draw a meridian circle passing through the magnetic pole and complete it round the earth so as to divide the earth into two

halves. At all points in this meridian circle, the needle might be expected to point due north, while in the one-half of the earth so divided it should point to the east, and in the other half to the west, of true north. In the next place let us imagine that the earth has two North Magnetic Poles or foci of equal strength, both being at the same latitude, while their difference in longitude is 180 degrees, and let us draw a complete circle of meridian passing through these poles. Let us start from a point in this circle under one of these poles, and pursue our journey eastwards along a circle of latitude. At first the needle will point due north. As we move eastwards the needle will point westwards to the pole we are leaving, until we come to a region half-way between the two poles, where it will be equally solicited by each, and will therefore again point due north. Let us call the space we have travelled over since we set out, A. As we proceed, the needle will now be under the predominant influence of the second pole, to our right, and will therefore point to the east, until we arrive at the meridian under the second pole. This second space which we have travelled over, let us call B. As we proceed, we pass through a space, C., where the needle again points to the west, until, being once more equally influenced by the two poles, it will point due north. After this, we pass through a space, D., of easterly variation, until we arrive once more at the point from which we started. Thus there are now four spaces instead of two, and these are shown in the figure; where the centre of the circle represents the North Geographical Pole of the earth, and its circumference the equator. If pole 2 be inferior in power to pole 1, the spaces B and C will be smaller in size than A and D."

Diagram illustrating the attractive influence of the two conjectured Magnetic Poles in the Northern Hemisphere.

Dr. Balfour Stewart states that this arrangement agrees very well with the results of observation, it being understood that the two poles are not precisely 180 degrees removed from one another in longitude. He considers that the fact that there are two lines of "no variation" extending through both hemispheres, and also an oval-shaped district in the Northern Hemisphere, the circumference of which has no variation, is inconsistent with the hypothesis of a single pole, but quite consistent with that of two poles. He assumes that one of these poles is in Northern America and the other in Northern Asia, the former being stronger than the latter. In the application of his illustration he supposes that we start from a point due south of the American pole and travel eastward. In space A, we have, through the attraction of the American pole, at first an increasing and then diminishing westerly variation, till at length we reach the line of no variation, when the tendency of the American pole to draw the needle to the west is counterbalanced by the tendency of the Asiatic pole to draw it to the east. We have then, in space B, an easterly variation, through the influence of the Asiatic pole, till, when we are due south of it, we have again no variation, this position being supposed by Dr. Balfour Stewart to be the western boundary of the oval. Thereafter, in space C, the Asiatic pole pulls the needle to the left, and we have westerly variation, until this tendency is overcome between spaces C and D, by the tendency of the American pole to pull the needle to the right, so that there is once again no variation, this position being, he

supposes, the eastern boundary of the oval. After this we have, in space D, through the influence of the American pole, an easterly variation, until we again arrive due south of the pole.

Dr. Balfour Stewart mentions that this argument has received corroboration from the fact that in the map of total force there are two foci of maximum force, one in Northern America and the other in Northern Asia, that in America being the stronger.

Of the two poles believed by Halley to exist in the Northern Hemisphere, we have hitherto referred only to the American Pole, which, for all practical purposes, has become known as the North Magnetic Pole. The Siberian or Asiatic Pole has not yet been discovered, and its existence is merely a matter of deduction; in fact, the question whether it really exists, and whether there are two magnetic poles in the Southern Hemisphere also, has popularly come to be ignored, and the pole discovered by Ross in the Northern Hemisphere, and the pole whose position is estimated in the Southern Hemisphere, have now become known generally as "The Magnetic Poles."

Although the latter are evidently the primary poles of magnetic influence, there is yet strong reason to agree with the views first promulgated by Halley, that the earth's magnetic system must be considered as possessing two poles in each hemisphere, and that the action of the magnetic needle in the Northern Hemisphere proves the existence of a magnetic pole in Northern Asia as well as in North America.

Even in an ordinary magnet, more than two poles are sometimes found to occur, so that the existence of more than two poles on the earth, viewed as a magnet, would not be surprising. As M. Guillemin says, in reference to ordinary bar magnets, "Sometimes a magnet has more than two poles beside the end poles, the existence of which we have just shown. Intermediate points are found where filings will stick, and which are also separated from each other by neutral lines. These points are called *consequent poles.*"*

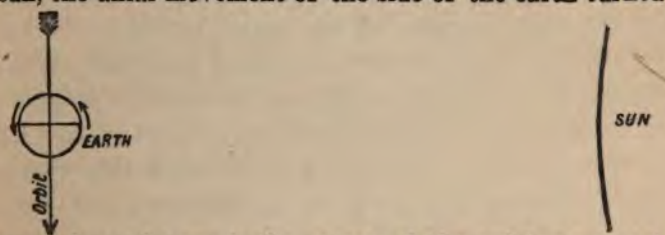
In a later part of his work,† Guillemin describes the method of magnetising a needle, by placing it inside a spiral coil of wire, through which an electric current is caused to flow, and he continues, "By this simple and wonderful method of magnetising, you may produce intermediate secondary poles at will, on the bars which you wish to magnetise; these are called 'consequent points,' as we have mentioned in our earlier chapter. As Arago was the first to perceive, all that is necessary for producing consequent points is, that after having coiled the wire in one direction round the tube for some distance, you coil it in the opposite direction. Each of the points opposite to the place where the direction of coiling is reversed, ought to be a secondary pole."

If we consider the subject of terrestrial magnetism in connection with this statement, we cannot overlook the fact that the axial movement of the earth on the side turned *away from* the sun, is—as regards any waves or currents projected from the sun to the earth—a

* *Electricity and Magnetism*, page 7. † do. page 357.

movement reverse in direction to the axial movement of the earth on the side turned *towards* the sun. If the axial movement of the earth is considered *as viewed from the sun*, and the Northern Hemisphere assumed to be uppermost, it is evident that, on the side of the earth turned towards the sun, the movement is from left to right. A place on the earth would come into view on the left side, and pass out of view on the right side. On the side of the earth turned away from the sun, the opposite must be the case. The movement is from right to left. A place passes from view on the right side, and it does not come into view till it reaches the left side.

Thus, in connection with the electrical waves from the sun, the axial movement of the side of the earth turned



away from the sun is the *reverse* of the axial movement of the side facing the sun. Although the former side is sheltered from the direct impact of electrical currents, it seems not improbable that, if the impact of the currents has the effect of magnetising the earth as a whole, this reverse movement may have an effect to some extent analogous to that stated by Guillemin to result from reversing the direction of a spiral coil of wire through which an electric current is sent in magnetising a steel needle. That is to say, a not improbable result would

be the production of two "consequent points." Such points if produced, might be expected to occur—like the primary magnetic poles, and for the same reason—in the neighbourhood of the Arctic and Antarctic circles respectively, and at a distance of about 180 degrees of longitude from the primary poles. The exact locality would be decided (as Guillemin states is always the case in natural magnets) by the internal structure and surface irregularities.*

We might suppose that, as in the magnetization of a steel bar, any such "consequent points" occurring on the earth considered as a magnet, should attract the opposite end of the needle from that attracted by the corresponding primary pole. If, however, we keep in mind that in the magnetization of the earth, according to our hypothesis, it is the object magnetised itself and not the electric current which rotates, and in which the direction of rotation is, so to speak, reversed every 12 hours, we must conclude that in the case of the earth this cannot be so. During 12 hours of the day the movement of the portion of the earth in which any "consequent point" may be situated, is from left to right, beneath the conjectured electrical current, and during the succeeding 12 hours, from right to left, sheltered from the current. If the direct impact of the current induces the formation of a pole attracting say, the north indicating end of the needle, the ensuing reverse movement can only, we should suppose, have the effect of weakening the power of attraction during the brief interval until the direct movement recommences.

* *Electricity and Magnetism*, p. 12.

We have suggested that the earth's magnetism is due to the earth's rotation combined with its swift orbital movement across the electric waves from the sun. We must not, however, ignore the fact that it is quite possible that the earth's magnetism may be due to the relatively slower rotatory movement of the earth in these electric waves, the earth being, as it were, a huge dynamo armature. In this case the reverse movement might also be different from what we have suggested above, namely, that the one-half of the earth facing the direction of its orbital movement is rotating *towards* the sun, while the other half is rotating *away from* the sun.

We have seen in Chapter III., that, on one theory of the earth's magnetism, electric currents circulate from east to west over the whole earth, and the result would be that on the one half of the earth these currents would move with the solar currents, while in the opposite hemisphere they would move against them. Assuming that theory to be correct, this might naturally be expected to produce some magnetic change, as a somewhat analagous set of conditions is set up to that whereby absorption lines in star spectra are displaced by the star's motion in the line of sight towards or away from the earth. This might explain in a simple manner the conjectured existence of two similar magnetic poles in each hemisphere. Moreover, as mentioned in Chapter VI., the magnetic axis of the earth sways to and fro, towards and away from the sun, thus slowly altering the manner in which the earth-currents

meet the solar-electric waves. This also might well have a share in the daily movement of the poles.

Undoubtedly, the occurrence of more than one magnetic pole in each hemisphere must greatly increase the difficulty of deciding as to the direct cause of the changes connected with the varying declination and dip of the magnetic needle at different stations; as the direction of the needle must necessarily, in certain geographical positions, be decided by the influence of more than one magnetic pole. We shall in the following chapter consider whether the secular changes in declination at different stations in the Northern Hemisphere necessarily infer the existence of two magnetic poles in that hemisphere. For the Southern Hemisphere the data are altogether too fragmentary at present to enable us to draw any conclusion.

In order to prevent confusion we shall refer to the conjectured Asiatic or Siberian Magnetic Pole as the Asiatic focus, and to the corresponding magnetic pole in the Southern Hemisphere as the Southern focus, and shall continue to designate the American Pole as the North Magnetic Pole, and the pole whose position was estimated by Ross in the Southern Hemisphere as the South Magnetic Pole. It is agreed that the latter points are really the primary sources of magnetic attraction, and, whatever secondary sources may exist, these will no doubt continue to be generally known as the Magnetic Poles.

CHAPTER IX.

The secular changes in Declination at certain stations in the Northern Hemisphere, and their bearing on the question of the existence of two Magnetic Poles in that Hemisphere.

DR. G. D. E. WEYER, a German scientist, has been at great pains in preparing a series of tables shewing the changes in declination for several centuries, observed or calculated, for a number of stations in the Northern and Southern Hemispheres, and, by the assistance of these tables,* we have complied the following table† of secular changes in declination at various stations in the Northern Hemisphere. It has to be kept in mind that the earlier figures are, in most cases, merely calculated, but they may be accepted as approximately correct. We have placed the stations in the order of longitude, commencing with the farthest west and proceeding eastwards.

The first matter of notice in this Table is that in a large number of stations a time of no variation does not occur,—the needle never points to the true north. Out of eight stations in the American Continent this is the case in no less than five. In these, the variation is continuously westerly. The needle certainly swings pendulum-like, to and fro, but its range is very small and does not cover the true north. In Baltimore,

* Nova Acta Academiæ, Vol. 63. Halle, 1895. † See pages 72 and 73.

TABLE OF SECULAR CHANGES IN DECLINATION AT VARIOUS STATIONS IN THE NORTHERN HEMISPHERE COMPILED FROM DR WEYER'S CALCULATIONS AND RECORDS.

Fort Prince of Wales. Lat..... 58° 48′ N. Long.... 94° 12′ W.		York Factory. 57° 0′ N. 92° 26′ W.	Baltimore. 39° 18′ N. 76° 37′ W.	Cartagena. 10° 26′ N. 75° 34′ W.	New York. 40° 43′ N. 74° 0′ W.	Quebec. 46° 48′ N. 71° 14′ W.	Cambridge. 42° 23′ N. 71° 8′ W.	Boston. 42° 21′ N. 71° 4′ W.
Date.	Declin.	Declination.	Declination.	Declination.	Declination.	Declination.	Declination.	Declination.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
1500	14 17 W.	14 51 W.	2 31 W.	0 53 W.	6 54 W.	15 56 W.	7 7 W.	6 17 W.
1550	4 15 E.	1 34 E.	0 20 ,,	1 18 E.	4 50 ,,	12 26 ,,	7 44 ,,	6 59 ,,
1600	10 49 ,,	9 55 ,,	2 11 ,,	3 39 ,,	5 36 ,,	13 48 ,,	10 24 ,,	10 19 ,,
1650	3 20 W.	0 51 W.	5 30 ,,	5 42 ,,	8 3 ,,	18 1 ,,	11 35 ,,	11 52 ,,
1700	19 24 ,,	16 29 ,,	5 42 ,,	7 6 ,,	8 34 ,,	18 50 ,,	9 43 ,,	9 34 ,,
1750	16 6 ,,	16 14 ,,	2 31 ,,	7 35 ,,	6 22 ,,	15 2 ,,	7 16 ,,	6 29 ,,
1800	2 12 E.	0 26 ,,	0 20 ,,	7 3 ,,	4 44 ,,	12 16 ,,	7 30 ,,	6 41 ,,
1850	11 14 ,,	9 57 E.	2 11 ,,	5 36 ,,	6 4 ,,	14 37 ,,	10 5 ,,	9 55 ,,
1900	0 59 W.	1 10 ,,	5 30 ,,	3 31 ,,	8 24 ,,	18 37 ,,	11 36 ,,	11 54 ,,
Extremes...11° 19′ E. in 1589 and 1845 20° 54′ W. in 1717 & 1973		9° 59′ E. in 1596 and 1852 19° 0′ W. in 1724 and 1980	0° 23′ W. in 1552 and 1802 6° 10′ W. in 1677 and 1927	7° 35′ E. in 1748 3° 14′ W. in 2108	4° 43′ W. in 1563 and 1803 8° 45′ W. in 1683 and 1923	12° 16′ W. in 1562 and 1802 19° 11′ W. in 1682 and 1922	6° 58 w. in. 1515 and 1771 11° 36′ W. in 1643 and 1899	6° 2′ w. in 1772 11° 54′ W. in 1644 and 1900
No Var....1538, 1641, 1794 and 1897		1545, 1647, 1801 and 1903	Never.	1522 and 1976	Never.	Never.	Never.	Never.
Period between returns to same extreme..... 256 yrs.		256 years.	250 years.	720 years.	240 years.	240 years.	256 years.	256 years.

TABLE OF SECULAR CHANGES ETC.—*Continued.*

London or Kew.*		Paris.*	Bergen.	Berlin.	Tornea.	Alexandria.	S. Petersburg.	Astrakhan.	Tobolsk.	Cape Comorin.	Irkutsk.	Yakutsk.
Lat....	51° 28′ N.	48° 50′ N.	60° 24′ N.	52° 30′ N.	65° 51′ N.	31° 11′ N.	59° 56′ N.	46° 21′ N.	58° 12′ N.	8° 5′ N.	52° 17′ N.	62° 2′ N.
Long..	0° 19′ W.	2° 20′ E.	5° 18′ E.	13° 24′ E.	24° 14′ E.	29° 53′ E.	30° 19′ E.	48° 2′ E.	68° 16′ E.	77° 30′ E.	104° 15′ E.	129° 44′ E.
Date.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
1500	6 46 E.	2 19 E.	8 30 W.	8 54 E.	13 58 W.	8 20 E.	7 36 W.	8 17 W.	12 11 E.	17 48 W.	2 46 E.	2 52 W.
1550	11 13 ,,	8 25 ,,	2 52 E.	11 55 ,,	5 4 ,,	4 51 ,,	7 25 ,,	11 22 ,,	12 1 ,,	17 41 ,,	1 42 W.	9 2 ,,
1600	9 16 ,,	8 18 ,,	8 36 ,,	9 13 ,,	7 23 ,,	0 29 W.	2 13 ,,	13 1 ,,	7 43 ,,	15 10 ,,	1 47 ,,	8 14 ,,
1650	1 39 ,,	2 1 ,,	5 37 ,,	1 49 ,,	14 18 ,,	6 14 ,,	1 44 E.	12 56 ,,	2 21 ,,	10 51 ,,	2 41 E.	2 52 ,,
1700	8 51 W.	7 51 W.	4 28 W.	7 28 W.	6 3 ,,	10 51 ,,	0 22 W.	11 11 ,,	0 16 W.	5 49 ,,	2 2 ,,	9 2 ,,
1750	18 25 ,,	17 13 ,,	16 17 ,,	15 4 ,,	6 12 ,,	13 7 ,,	5 57 ,,	8 0 ,,	1 46 E.	1 16 ,,	2 19 W.	8 14 ,,
1800	23 34 ,,	22 11 ,,	23 31 ,,	18 4 ,,	14 19 ,,	12 24 ,,	8 19 ,,	3 52 ,,	6 58 ,,	1 41 E.	0 58 ,,	2 52 ,,
1850	22 24 ,,	20 44 ,,	22 19 ,,	15 22 ,,	7 12 ,,	8 55 ,,	4 34 ,,	0 34 E.	11 38 ,,	2 19 ,,	3 11 E.	9 2 ,,
1900	15 21 ,,	13 28 ,,	13 18 ,,	7 58 ,,	5 11 ,,	3 35 ,,	0 45 E.	4 38 ,,	12 26 ,,	0 29 ,,	1 8 ,,	8 14 ,,
Extremes..	11° 20′ E. in 1560	9° 12′ E. in 1574	8° 43′ E. in 1608	11° 55 E. in 1550	3° 38′ W. in 1569, 1725 and 1881	9° 10′ E. in 1463	1° 50′ E. in 1658 and 1928	9° 34′ E. in 2023	12° 43′ E. in 1523 and 1883	2° 24′ E. in 1837	3° 22′ E. in 1670 and 1860	2° 50′ W. in 1647, 1797 and 1947
	23° 54′ W. in 1816	22° 28′ W. in 1814	24° 7′ W. in 1818	18° 5′ W. in 1800	14° 21′ W. in 1647, 1803 and 1959	13° 13′ W. in 1763	8° 21′ W. in 1523 and 1793	13° 12′ W. in 1623	0° 16′ W. in 1703	18° 4′ W. in 1522	2° 44′ W. in 1575 and 1765	10° 35′ W. in 1572, 1722 and 1872
No Var...	1658, 1973	1661 and 1967	1680 and 1956	1660 and 1943	Never.	1596 and 1931	1620, 1696 and 1890	1843	1686 and 1720	1767 and 1907	1531, 1620, 1721 and 1810	Never.
Period between returns to same extreme.....	512 yrs.	480 yrs.	420 yrs.	500 yrs.	156 yrs.	600 yrs.	270 yrs.	800 yrs.	360 yrs.	630 yrs.	190 yrs.	150 yrs.

* See Appendix No. I. for any discrepancies between Weyer's figures for London or Kew or Paris, and the actual figures.

TABLE OF SECULAR CHANGES IN DECLINATION AT VARIOUS STATIONS IN THE NORTHERN HEMISPHERE COMPILED FROM DR WEYER'S CALCULATIONS AND RECORDS.

Fort Prince of Wales. Lat..... 58° 48′ N. Long.... 94° 12′ W.		York Factory. 57° 0′ N. 92° 26′ W.	Baltimore. 39° 18′ N. 76° 37′ W.	Cartagena. 10° 26′ N. 75° 34′ W.	New York. 40° 43′ N. 74° 0′ W.	Quebec. 46° 48′ N. 71° 14′ W.	Cambridge. 42° 23′ N. 71° 8′ W.	Boston. 42° 21′ N. 71° 4′ W.
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1550	4 15 E.	1 34 E.	0 20 ,,	1 18 E.	4 50 ,,	12 26 ,,	7 44 ,,	6 59 ,,
1600	10 49 ,,	9 55 ,,	2 11 ,,	3 39 ,,	5 36 ,,	13 48 ,,	10 24 ,,	10 19 ,,
1650	3 20 W.	0 51 W.	5 30 ,,	5 42 ,,	8 3 ,,	18 1 ,,	11 35 ,,	11 52 ,,
1700	19 24 ,,	16 29 ,,	5 42 ,,	7 6 ,,	8 34 ,,	18 50 ,,	9 43 ,,	9 34 ,,
1750	16 6 ,,	16 14 ,,	2 31 ,,	7 35 ,,	6 22 ,,	15 2 ,,	7 16 ,,	6 29 ,,
1800	2 12 E.	0 26 ,,	0 20 ,,	7 3 ,,	4 44 ,,	12 16 ,,	7 30 ,,	6 41 ,,
1850	11 14 ,,	9 57 E.	2 11 ,,	5 36 ,,	6 4 ,,	14 37 ,,	10 5 ,,	9 55 ,,
1900	0 59 W.	1 10 ,,	5 30 ,,	3 31 ,,	8 24 ,,	18 37 ,,	11 36 ,,	11 54 ,,
Extremes...11° 19′ E. in 1589 and 1845 20° 54′ W. in 1717 & 1973		9° 59′ E. in 1596 and 1852 19° 0′ W. in 1724 and 1980	0° 23′ W. in 1552 and 1802 6° 10′ W. in 1677 and 1927	7° 35′ E. in 1748 3° 14′ W. in 2108	4° 43′ W. in 1563 and 1803 8° 45′ W. in 1683 and 1923	12° 16′ W. in 1562 and 1802 19° 11′ W. in 1682 and 1922	6° 58 w. in. 1515 and 1771 11° 36′ W. in 1643 and 1899	6° 2′ W. in 1772 11° 54′ W. in 1644 and 1900
No Var....1538, 1641, 1794 and 1897		1545, 1647, 1801 and 1903	Never.	1522 and 1976	Never.	Never.	Never.	Never.
Period between returns to same extreme..... 256 yrs.		256 years.	250 years.	720 years.	240 years.	240 years.	256 years.	256 years.

TABLE OF SECULAR CHANGES ETC.—*Continued.*

London or Kew.*		Paris.*	Bergen.	Berlin.	Tornea.	Alexandria.	S. Petersburg.	Astrakhan.	Tobolsk.	Cape Comorin.	Irkutsk.	Yakutsk.
Lat....	51° 28′ N.	48° 50′ N.	60° 24′ N.	52° 30′ N.	65° 51′ N.	31° 11′ N.	59° 56′ N.	46° 21′ N.	58° 12′ N.	8° 5′ N.	52° 17′ N.	62° 2′ N.
Long..	0° 19′ W.	2° 20′ E.	5° 18′ E.	13° 24′ E.	24° 14′ E.	29° 53′ E.	30° 19′ E.	48° 2′ E.	68° 16′ E.	77° 30′ E.	104° 15′ E.	129° 44′ E.
Date.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.	Declin.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
1500	6 46 E.	2 19 E.	8 30 W.	8 54 E.	13 58 W.	8 20 E.	7 36 W.	8 17 W.	12 11 E.	17 48 W.	2 46 E.	2 52 W.
1550	11 13 ,,	8 25 ,,	2 52 E.	11 55 ,,	5 4 ,,	4 51 ,,	7 25 ,,	11 22 ,,	12 1 ,,	17 41 ,,	1 42 W.	9 2 ,,
1600	9 16 ,,	8 18 ,,	8 36 ,,	9 13 ,,	7 23 ,,	0 29 W.	2 13 ,,	13 1 ,,	7 43 ,,	15 10 ,,	1 47 ,,	8 14 ,,
1650	1 39 ,,	2 1 ,,	5 37 ,,	1 49 ,,	14 18 ,,	6 14 ,,	1 44 E.	12 56 ,,	2 21 ,,	10 51 ,,	2 41 E.	2 52 ,,
1700	8 51 W.	7 51 W.	4 28 W.	7 28 W.	6 3 ,,	10 51 ,,	0 22 W.	11 11 ,,	0 16 W.	5 49 ,,	2 2 ,,	9 2 ,,
1750	18 25 ,,	17 13 ,,	16 17 ,,	15 4 ,,	6 12 ,,	13 7 ,,	5 57 ,,	8 0 ,,	1 46 E.	1 16 ,,	2 19 W.	8 14 ,,
1800	23 34 ,,	22 11 ,,	23 31 ,,	18 4 ,,	14 19 ,,	12 24 ,,	8 19 ,,	3 52 ,,	6 58 ,,	1 41 E.	0 58 ,,	2 52 ,,
1850	22 24 ,,	20 44 ,,	22 19 ,,	15 22 ,,	7 12 ,,	8 55 ,,	4 34 ,,	0 34 E.	11 38 ,,	2 19 ,,	3 11 E.	9 2 ,,
1900	15 21 ,,	13 28 ,,	13 18 ,,	7 58 ,,	5 11 ,,	3 35 ,,	0 45 E.	4 38 ,,	12 26 ,,	0 29 ,,	1 8 ,,	8 14 ,,
Extremes..	11° 20′ E. in 1560	9° 12′ E. in 1574	8° 43′ E. in 1608	11° 55 E. in 1550	3° 38′ W. in 1569, 1725 and 1881	9° 10′ E. in 1463	1° 50′ E. in 1658 and 1928	9° 34′ E. in 2023	12° 43′ E. in 1523 and 1883	2° 24′ E. in 1837	3° 22′ E. in 1670 and 1860	2° 50′ W. in 1647, 1797 and 1947
	23° 54′ W. in 1816	22° 28′ W. in 1814	24° 7′ W. in 1818	18° 5′ W. in 1800	14° 21′ W. in 1647, 1803 and 1959	13° 13′ W. in 1763	8° 21′ W. in 1523 and 1793	13° 12′ W. in 1623	0° 16′ W. in 1703	18° 4′ W. in 1522	2° 44′ W. in 1575 and 1765	10° 35′ W. in 1572, 1722 and 1872
No Var...	1658, 1973	1661 and 1967	1680 and 1956	1660 and 1943	Never.	1596 and 1931	1620, 1696 and 1890	1843	1686 and 1720	1767 and 1907	1531, 1620, 1721 and 1810	Never.
Period between returns to same extreme.....	512 yrs.	480 yrs.	420 yrs.	500 yrs.	156 yrs.	600 yrs.	270 yrs.	800 yrs.	360 yrs.	630 yrs.	190 yrs.	150 yrs.

* See Appendix No. I. for any discrepancies between Weyer's figures for London or Kew or Paris, and the actual figures.

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of these stations also, a time of no variation occurs periodically. As we move eastwards a difference is again evident. We find that at Tornea, which is nearly as far north as the Arctic circle, the declination is always westerly, and the range of movement only 10° 33′. At St. Petersburg, on the other hand, the needle points to the true north with exceptional frequency, while the range of the declination covers from 1° 50′ E., to 8° 21′ W., that is, 10° 11′. At Yakutsk, the extreme easterly station, which lies at about 62° N. and 130° E., the declination is always westerly, varying from 2° 50′ to 10° 35′; while at Irkutsk, which lies about 10° farther south, and about 25½° farther west, there is a small range of 6° 6′ varying from 3° 22′ E. to 2° 44′ W.

If we now take the position at which the magnetic pole was found in 1831 (70° 5′ N., and 96° 43′ W.), we find that its longitudinal separation from Yakutsk was, at that date, about 133½°, measuring from Yakutsk in an easterly direction; so that if the needle at Yakutsk pointed towards that pole it must then have shewn an easterly variation. The variation at Yakutsk, however, is always quite appreciably westerly. The longitudinal separation of the pole from Irkutsk in 1831 was 159° 5′, and, as viewed from Irkutsk, this separation is also in an easterly direction. We have seen that the American records indicate that the pole never moves quite so far east as Baltimore, which is in longitude 76° 37′ W. If, however, we suppose that that longitude is the *extreme* of the pole's easterly movement, we get the longitudinal separation from Irkutsk, when the pole is in its extreme

easterly position, as 179° 11′, measuring from Irkutsk easterly, so that such trifling variation, if any, as might then occur, should be easterly. The needle at Irkutsk should, therefore, never have a *westerly* variation, yet it has in reality nearly as large a westerly variation (2° 44′), as an easterly variation (3° 22′). As Irkutsk is in fairly high northern latitude (52° 17′ N.), we can scarcely suppose that the South Magnetic Pole could account for this. At Tobolsk, in latitude 58° 12′ N. and longitude 68° 16′ E., the needle moves from 12° 43′ E. to 0° 16′ W., a range of 12° 59′. The longitudinal separation of this station from the position assigned for the North Magnetic Pole in 1831 is 164° 59′ measuring westwards from Tobolsk. The needle should therefore, if it is attracted towards that Pole, shew an appreciable westerly variation, while the extreme westerly variation which occurs there is only 0° 16′ W., and in 1831 there was a large easterly variation.

Can these discrepancies be accounted for by the existence of a powerful and permanent source of deflection other than a magnetic pole—such as an extensive range of magnetic rock—lying to the west of Yakutsk, and to the east of Tobolsk?

If this were the explanation, the movements of the needle at these Asiatic stations would *harmonize* with the movements of the pole, as the source of deflection would be fixed and immovable. If a needle is acted upon by two magnets one of which is immovable in relation to the needle while the position of the other changes, the needle must necessarily respond to the

movements of the latter, even although permanently deflected by the fixed source of attraction.

Judging by the American records, the magnetic pole between 1850 and 1900 lay longitudinally between York Factory (92° 30′ W.) and Baltimore (76° 37′ W.), and it was moving westward in relation to all the American stations, with the single exception of Cartagena, which, as it lies very far south, is no doubt subject to disturbing influences on the part of the South Magnetic Pole, and may, therefore, in this matter be disregarded. If then at the American stations the needle was drawn *westward*, it would certainly at Irkutsk of all places—Irkutsk being separated from Baltimore by almost exactly 180 degrees of longitude—have been drawn *eastward* if acted upon by the same source of attraction. During the whole of that period, however, the needle at Irkutsk moved westward, the westerly movement during the period being 2° 3′, the declination changing from 3° 11′ E. in 1850, to 1° 8′ E. in 1900.

It appears to be impossible to account for the movements of the needle at these eastern stations other than on the supposition that they are influenced by some different source of attraction than the American Magnetic Pole, and that this attractive force is itself, like the American Pole, of a moving character; and therefore that it also can be nothing else than a terrestrial magnetic pole, although of considerably weaker influence than the American Pole. There seem to be overwhelming difficulties in accounting for the needle's movements on any other supposition.

If then we conclude that an Asiatic focus constituting a magnetic pole really exists, although not yet discovered, the next question we have to consider is what is its geographical position. As the needle in Yakutsk points permanently westward, we must conclude that this pole lies to the west of longitude 129° 44′ E.; and as the needle in Irkutsk swings 3° 22′ to the east and 2° 44′ to the west, we may suppose that the central meridian intersecting this pole's longitudinal movement lies slightly to the east of Irkutsk. We may therefore suppose that the position of this pole in longitude, must be about 110° E., and it has been estimated (as mentioned by Captain Creak, F.R.S., in his presidential address to the Geographical Section of the British Association in 1903), that the latitude is about 70° north, being practically the latitude assigned by Ross to the North Magnetic Pole. This focus is probably situated in the North-west of Siberia, and possibly at a considerably higher latitude than that estimated.

CHAPTER X.

The nature of the secular movement of the North Magnetic Pole, as indicated by the secular change of the needle in declination at various stations in North America. The period of the secular movement of the North Magnetic Pole.

FROM the table of movements in declination given in the preceding chapter, it will be seen that there is an extraordinary difference in the period taken by the needle in different localities in moving from one extreme of its variation to the opposite extreme and back again. At Yakutsk the period is 150 years, at Tornea 156, at Irkutsk 190, at New York and Quebec 240, at Baltimore 250, and at Fort Prince of Wales, York Factory, Cambridge (U.S.) and Boston, it is 256 years. These are the shorter periods. With the longer periods we have Astrakhan 800 years, Cartagena 720, Cape Comorin 630, Alexandria 600, London 512, Berlin 500, and Paris 480. Thus in the stations specified, there is a difference in this respect of no less than 650 years from the minimum of 150 at Yakutsk to the maximum of 800 at Alexandria. It will be noticed that places near each other differ to a comparatively small extent in their period. This shews that notwithstanding the great discrepancy, some definite causes are at work producing the different results. Now, if the magnetic poles have a secular movement at all,

this movement must be accomplished in a certain definite period; and if these poles produce the movements of the needle, how can these excessive differences be accounted for?

We can best get at the actual secular movement of the poles by means of the records for stations in their near neighbourhood. Fort Prince of Wales, in lat. 58° 41′ N., and long. 94° 12′ W.; and York Factory, in lat. 57° 0′ N., and long. 92° 30′ W., are therefore the best stations to give us an indication of the movement of the North Magnetic Pole. We may consider these stations as practically free from the disturbing influence of the other magnetic poles.

The following statement shews the date of occurrence, and the amount of the extreme declination at these stations, and also the dates of occurrence of no variation, the dates being those specified by Dr. Weyer from records and estimates.

	Fort Prince of Wales.	*York Factory.*
Extremes,	11° 19′ E., 1589,* 1845. 20° 54′ W., 1717.	9° 59′ E., 1596,* 1852. 19° 0′ W., 1724.
No variation,	1538,* 1641, 1794, 1897.*	1545,* 1647, 1801, 1903.*

We may suppose that in 1538 the pole was on the meridian of Fort Prince of Wales, and that seven years later it reached the meridian of York Factory, as at these dates "no variation" occurred at these stations respectively. In 1589 the pole had reached its extreme easterly position in relation to the former station, and seven years later it reached its extreme easterly position

* Weyer's Estimate.

in relation to the latter station. We have no particulars of the dip, but there is no difficulty, so far, in conjecturing the movement to be a curve. The next date is 1641, when there was again no variation at Fort Prince of Wales, and here the difficulty begins. How is it possible for the pole, which had moved to the east of York Factory, to return to the meridian of Fort Prince of Wales, which lies to the west of York Factory, without first passing over either the meridian of York Factory or the opposite meridian. The corresponding date of no variation at York Factory is 1647, which is six years later than its occurrence at Fort Prince of Wales, and yet the pole must undoubtedly have been to the east of York Factory in 1596, when the extreme easterly variation occurred. How then could it have moved to the west without first producing "no variation" at York Factory at an earlier date than at the other station.

This is certainly puzzling on the first glance, and yet there seems to be a very simple explanation.

We have got into the way of thinking of the Magnetic Pole as a definite point on the earth's surface, a spot which we can stand upon. Ross has given us the actual geographical position of the American Pole, not only to degrees, but to minutes, and indeed, some authorities specify even the seconds (70° 5′ 17″ N. Lat., 96° 43′ 48″ W. Long.). While in a certain sense this is no doubt correct, in another sense it seems to be misleading. Even in an ordinary bar magnet the poles are of appreciable size, and in comparison with the magnet they are of considerable size. If, then, the earth is a

magnet, what must be the size of its poles? It can scarcely be questioned that they must cover a large area.

On the analogy of a bar magnet let us suppose the terrestrial magnetic poles to be elliptical spaces covering some degrees of the earth's surface, and let us, on this supposition, see how the movements of the needle at Fort Prince of Wales and York Factory can be accounted for.

Let us suppose that the pole rotates on its own axis in a direction, as viewed from the south, opposite to the motion of the hands of a clock. Let us construct a circle representing this movement, and draw an elliptical figure as a diameter across it, representing the area, so to speak, of the magnetic pole. Let us place Fort Prince of Wales and York Factory beneath the circle with lines from each of them through the circle representing their meridians. For the sake of simplicity, and to enable us to follow the movements of the extremities, and see how the pole would be likely in its changing position to influence the needle at the stations under consideration, we shall distinguish the two extremities of the figure representing the magnetic pole by the letters A and B.

We find that this exactly accounts for the movements of the needle. Thus when either extremity is on the meridian of the station, or both extremities are equidistant from the meridian of the station, there is no variation; with the extremities in the intermediate positions, the greatest variation occurs.

This also explains another difficulty. When the pole

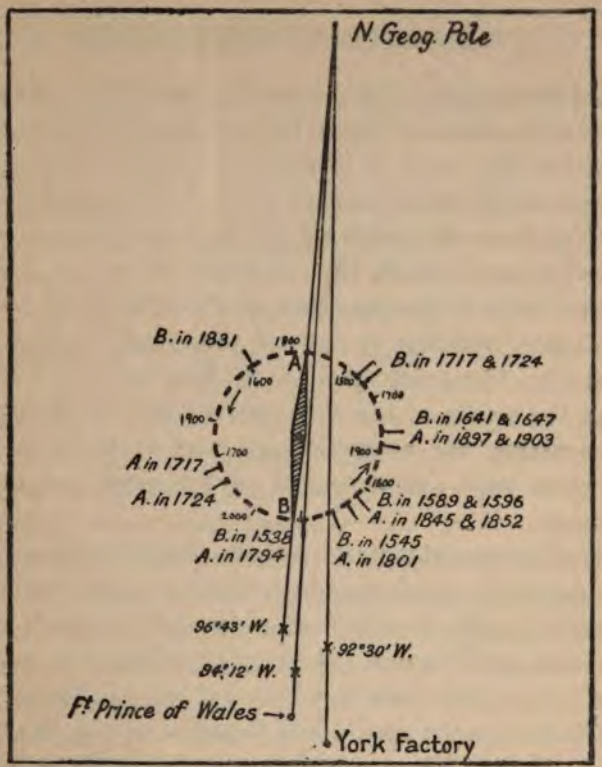

Diagram representing hypothetical secular circuit of the North Magnetic Pole, as indicated by the secular changes in declination at Fort Prince of Wales (58° 41′ N., 94° 12′ W.), and at York Factory (57° 0′ N., 92° 30′ W.). The shaded portion represents the N. Magnetic Pole, and the dotted circle the circuit of its extremities A and B. The dates for A are inside, and for B outside, the circle.

Fort Prince of Wales.—Total range of needle, 32° 13′.

Extreme E.	(11° 19′ E.)	...	1589	...	...	...	1845	...	...	
No Variation	...	1538	...	1641	...	1794	...	1897	...	
Extreme W.	(20° 54′ W.)	...	...	...	1717	...	...	...	1973	
Mean Direction	(4° 47′ W.)	1525	...	...	1653	...	1781	...	...	1909 ...

York Factory.—Total range of needle, 28° 0′.

Extreme E.	(9° 0′ E.)	...	1596	...	...	...	1852	...	...	
No Variation	...	1545	...	1647	...	1801	...	1903	...	
Extreme W.	(19° 0′ W.)	...	...	...	1724	...	...	...	1980	
Mean Direction	(5° 0′ W.)	1532	...	...	1660	...	1788	...	...	1916 ...

The maximum yearly change of direction at both stations occurs at the time of "mean direction," and is 23·5′ and 21·1′ respectively.

was discovered in 1831, the needle at both these stations pointed eastwards of north, and yet Ross found the pole to the west of north in relation to both stations. Fort Prince of Wales is in longitude 94° 12′ W., and York Factory is in longitude 92° 30′ W., while the pole was found in longitude 96° 43′ west, that is to say, somewhat farther west of the meridian of Fort Prince of Wales than that meridian is west of the meridian of York Factory. The point specified by Ross might well have been the centre of the ellipse which we have shewn as representing the magnetic pole, and as being in accordance with the movement of the needle, at these stations.

This appears to indicate that the secular movement of the magnetic pole is really a revolution on its own axis —that the pole is, as it were, pivoted at the centre, and revolving on the pivot just exactly as a magnetic needle itself does. The nearer extremity has, of course, the chief effect on the needle, and thus the secular changes are produced. There would thus appear, so far as these returns shew, to be little, if any, change of position of the central part of the pole. At least, it does not seem necessary that there should be any such change to explain the secular movement of the needle at these two stations.

Further corroboration of the rotatory nature of the polar secular circuit is furnished by Weyer's Tables, which show that the mean yearly variation of the needle, at the two stations, is greatest about the time of "no variation," and least about the time of

greatest easterly and westerly declination — which must necessarily be the case if the motion is circular.

Starting with A and B in their "equidistant" position, the needle will be pointing approximately between them. But as A—or B, as the case may be—sweeps onward on its circuit, with a motion nearly in the line of the magnetic meridian, at first the needle will be attracted to the quickly approaching extremity, and thus exhibit a yearly variation, large at first, which gradually diminishes as the influence of the other extremity weakens, and as the one to which it is attracted moves forward, so to speak, to meet it.

Finally, as the extremity approaches to its nearest to the needle, its motion becomes more and more at right angles to the magnetic meridian, until at last the whole annual secular motion is altogether thus at right angles, again causing the annual variation to be at a maximum. After that the process is reversed.

From this illustration of the apparent secular movement of the pole, it would appear that it revolves on its axis not in the time given by Dr. Weyer as the period of the movement of the needle at Fort Prince of Wales and York Factory, but in twice that period. Dr. Weyer's estimate of the time of the needle's movement is 256 years, and, working on that basis, we find that that is the time occupied in the extremities A and B changing positions; the actual time of the polar circuit being therefore 512 years, which, curiously enough, is the time estimated by Dr. Weyer as that occupied by

the complete movement of the needle at London. And the annual *angular* change is thus about 0·7°.

As the stations in North America may all be considered as dominated by this pole, we may notice how the conjectured secular movement of the pole fits in with the movement of the needle at each of the other North American Stations. The farthest west of these stations is Baltimore, which is in long. 76° 37′ W., and as the most easterly position of the needle in that station is 0° 21′ W., we may conclude that the pole never extends quite so far east as the meridian of Baltimore; although it is quite possible that the movement of the needle at Baltimore may be otherwise affected. Let us assume that the polar movement extends eastwards as far as say 78° W. longitude, and see how such a movement as we have suggested suits the movement of the needle at Baltimore, New York, Quebec, Cambridge, and Boston. We shall represent the movement as in the preceding diagram, and the results are shown on the opposite page.

When we keep in mind that the dates of the extremes of declination,—and, consequently, the period of the pole's revolution,—are only approximately correct, it will be seen that the position of the pole at the dates of extreme variation answers the requirements with surprising accuracy. So far, therefore, as the information enables us to judge, it would appear that the secular movement of the North Magnetic Pole is somewhat such as we have described.

It is evident that the European stations will be affected to a varying extent by both the North Magnetic

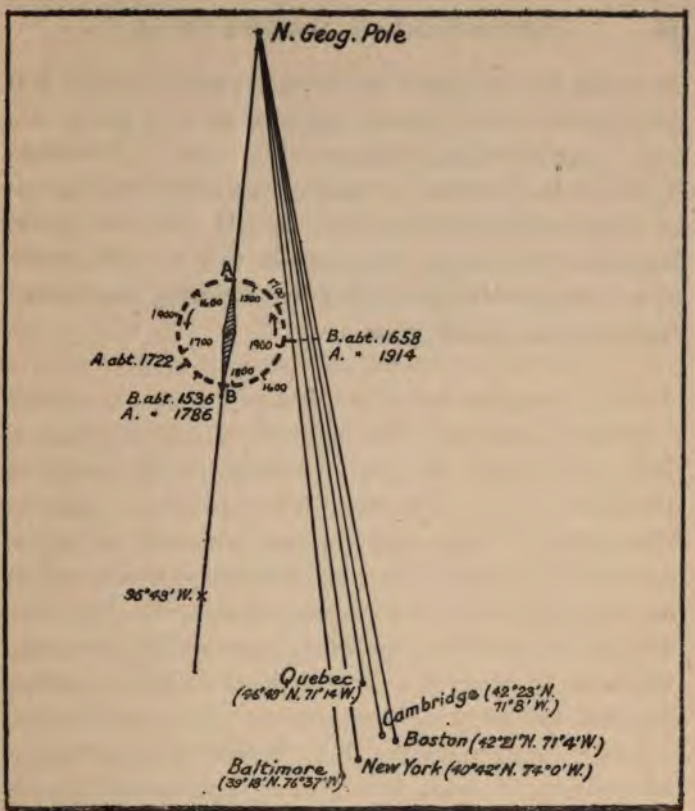

Diagram representing hypothetical secular circuit of the North Magnetic Pole, as indicated by the secular changes in declination at certain North American stations.

The shaded area represents the North Magnetic Pole, and the dotted circle the circuit of its extremities A and B. The dates for A are inside, and for B outside, the circle.

	Furthest E.	Furthest W.	Mean Direction.	Total Range.
Boston	(6° 2'W.) 1515, 1772	(11°54'W.) 1644, 1900	(8°58'W.) 1580, 1708, 1836	4¾°
Cambridge	(6°58'W.) 1515, 1771	(11°36'W.) 1643, 1899	(9°17'W.) 1579, 1707, 1835	4¼°
Quebec	(12°16'W.) 1562, 1802	(19°11'W.) 1682, 1922	(15°43'W.) 1622, 1742, 1862	7°
New York	(4°43'W.) 1563, 1803	(8°45'W.) 1683, 1923	(6°44'W.) 1623, 1743, 1863	4°
Baltimore	(0°21'W.) 1552, 1802	(6°10'W.) 1677, 1927	(3°15'W.) 1615, 1740, 1865	5¾°

Pole and the Asiatic focus, being sometimes under the domination of the former, and sometimes of the latter, and frequently partly influenced by both. It would, therefore, be profitless to consider the secular variations at these stations in connection merely with the North Magnetic Pole alone. The subject will be considered, in a subsequent chapter, after investigating the movement of the Asiatic focus.

CHAPTER XI.

The secular period of the Asiatic focus as indicated by the secular change of the needle in declination at a station in Siberia.

WE have come to the conclusion that although it is not yet actually discovered, it seems necessary to postulate a magnetic pole somewhere about longitude 110° E. On no other supposition than that there is an Asiatic as well as an American magnetic pole, can the movements of the needle in the Northern Hemisphere, so far as we can judge, be reasonably accounted for. As there are no particulars of the secular changes in dip for the eastern stations available to the writer, he is unable to form any satisfactory opinion as to the latitude of this conjectured pole; but, as mentioned in a preceding chapter, it has been estimated that its latitude is about 70° north. We can form some idea as to the period occupied by this pole in its secular revolution in the same manner as we have done in the case of the North Magnetic Pole, although the data available are, of course, much weaker. It seems likely that the magnetic needle at Yakutsk, Irkutsk, and Tobolsk, are mainly dominated by this pole. As regards Yakutsk and Irkutsk, there seems to be no doubt that they are mainly influenced by the Asiatic focus. As regards Tobolsk, however, the varying

declination, and the great difference in the period between the recurrence of the same extreme in declination from the corresponding periods at the other two stations seem to shew that the North Magnetic Pole also has considerable effect in deciding the position of the needle, although the chief factor certainly appears to be the Asiatic focus. The period between the recurrence of the same extreme in declination is at Yakutsk, 150 years, at Irkutsk, 190 years, while at Tobolsk it is 360 years.

As Irkutsk is very close to the meridian on which we are assuming the Asiatic focus to be, it is best, in view of the difference in these periods, to make use of it alone in estimating the period of the secular movement of this pole. The needle is, at Irkutsk, more likely to be entirely influenced by the Asiatic focus than at either of the other stations. Let us, therefore, form a circle representing the secular movement of the Asiatic focus, and, as before, draw an elliptical figure as a diameter across it representing the focus area, and see how the pole, or focus, must actually move to account for the changes in declination occurring at Irkutsk. As the extreme westerly variation at Irkutsk (2° 44′ W.) is slightly smaller than the extreme easterly variation (3° 22′ E.), we shall make the meridian of Irkutsk pass through this circle a little to the west of the central point.

It would appear from the returns for Irkutsk,—assuming that the movement of the magnetic needle there is virtually influenced almost exclusively by the Asiatic focus,—that the period of the secular movement of this pole is about 380 years, that being the interval

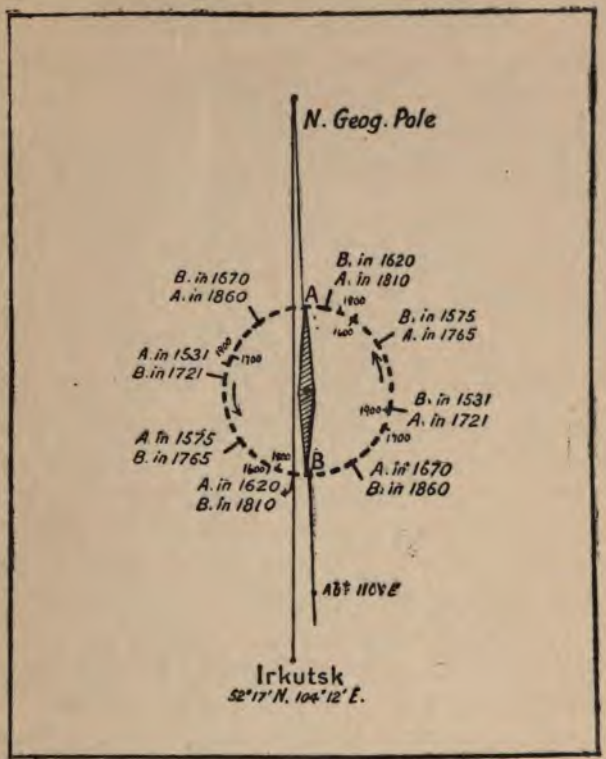

Diagram representing hypothetical secular circuit of the Asiatic Focus, as indicated by the secular changes in declination at Irkutsk (52° 17′ N., 104° 12′ E.

The shaded portion represents the Asiatic Focus, and the dotted circle the circuit of its extremities. The dates for A are outside, and for B inside, the circle.

Irkutsk.—Total range of needle, 6° 6′.

Extreme E.	(3° 22′ E.)	...	...	...	1670	...	...	...	1860	
No Variation	...	1531	...	1620	...	1721	...	1810	...	
Extreme W.	(2° 44′ W.)	...	1575	...	...	...	1765	...	...	
Mean Direction	(0° 19′ E.)	...	...	...	1623	1718	...	...	1813	...

between the returns of the same extremity of the elliptical focus to the same point of the circuit.

It will be noticed that, as in the case of the North Magnetic Pole, the northward movement of the focus appears to occur on the eastern side of the circuit, the southward movement on the western side. As the North Magnetic Pole and the Asiatic focus are longitudinally on opposite sides of the earth, this, in a sense, results in their movements being reversed. They are, as it were, back to back, and thus, if one were facing either pole on its southern side, the northward secular movement at that pole would occur on one's right, while at the other pole it would be on the left. But, as the sun moves from east to west, we find that the northward movement in both cases is on the side of the circuit first receiving the sun, the southward movement on the side last turning away from the sun. This is the converse of the daily movement, as revealed by the daily change of the needle at Kew, as described in Chapter VI.

As the Asiatic focus is much weaker in influence than the North Magnetic Pole, and as there are no returns available in its near neighbourhood (other than those for Irkutsk) which can be assumed to be free from the disturbing influence of the North Magnetic Pole, it would be profitless to endeavour by diagram to trace out the influence of this focus at the various stations. At Yakutsk and Tobolsk the needle appears to be largely dominated by the Asiatic focus, and from this no doubt arises the permanent westerly variation at the former station, and the excessive easterly variation at the latter,

but the needle at these stations is also most likely influenced to an appreciable extent by the powerful attraction of the North Magnetic Pole, so that no certain conclusion as to the separate influence of the Asiatic focus can be come to.

We have now seen that there is reason to suppose that the North Magnetic Pole in its secular circuit occupies about 512 years, and the Asiatic focus about 380 years. Whether these periods are correct or not, it is impossible to say, but there appears, at any rate, to be strong reason to suppose that the secular circuit of these poles is accomplished in periods differing from each other to a very considerable extent. From this it necessarily follows that these poles will for many centuries be in different relations to each other, and, therefore, that their influence on the magnetic needle in districts affected to some extent by both will be continuously of a changing character. Were the period of the North Magnetic Pole and the Asiatic focus the same, then their varying influence on the needle would extend through a similar cycle at the various stations. But if the periods are different, the magnetic cycle at the separate stations must differ according to the relative position of the two sources of attraction, if the needle is to any extent affected by both. This is a matter of the utmost importance as explanatory of the varying periods of the needle's movement, and we shall consider it more fully in connection with certain of the stations at which the needle is manifestly to some extent affected by both these poles.

CHAPTER XII.

The difference in the period of the secular circuit of the North Magnetic Pole, and of the Asiatic Focus explanatory of the varying periods of the Magnetic cycle at different stations.

WE have seen that there is good reason for supposing that the North Magnetic Pole and the Asiatic focus occupy different periods in their secular circuits; that the secular circuit of the former is accomplished in about 512 years, and of the latter in about 380 years. The extent to which this will affect the relative position of the poles in their circuit is surprising. Let us suppose that at a certain station the needle is so affected by both poles that it will show "no variation" only when the American Pole is exactly at, let us say, the point A in its circuit, and the Asiatic Pole exactly at the point B in its circuit,—that these two things must occur simultaneously to produce "no variation." We may consider both poles as influencing the needle equally by either extremity, which would, of course, shorten the period of each by one-half. Notwithstanding this, the combination of circumstances required to produce "no variation" would be repeated only after an interval of something like 24,000 years—which is, curiously enough, approximately the period of the circuit of the geo-

graphical pole round the pole of the ecliptic. We may imagine such a case to be practically impossible. At the places where "no variation" occurs, through the combined influence of these poles, it will happen with the magnetic poles not merely at particular *points*, but in relative *arcs* of the circuit, the one pole having a certain effect in drawing the needle westward, the other pole a corresponding effect in drawing it eastward.

It is an exceedingly complex matter to judge of the relative attractive influence of two magnetic poles of the same character on a magnetic needle, one pole being stronger than the other. A very slight change of position of either pole may produce a considerable deflection in the needle. We may, however, endeavour to ascertain on the basis of the foregoing arguments what were the relative positions of these poles at the time of the occurrence of the extremes of variation in London, and at the date of no variation.

The following diagram illustrates this matter,—the movement of the poles being represented as brought out in the preceding enquiry. It is to be noted that London is longitudinally almost midway between the conjectured positions of the North Magnetic Pole and the Asiatic focus, and that the needle in London may therefore be supposed to be influenced by both poles to the extent of something like their respective intensities. It may further be noted that the preponderance of the westerly movement may naturally be accounted for by the greater strength of the American Pole.

It would appear that, in 1560, when the extreme

easterly variation occurred, and the influence of the Asiatic focus must therefore have predominated, the then north extremity of the American Pole pointed considerably to the west of the North Geographical Pole, and the then north extremity of the Asiatic focus, considerably to the east of the same point. In 1657, when no variation occurred in London, both poles seem to have stretched practically north-westward and south-eastward; while in 1818, when the extreme westerly variation occurred in London, the American Pole appears to have been not very far from the same position as in 1560 (when the extreme easterly variation occurred), but the Asiatic Pole was not far removed from a diametrically opposite position. Dr. Weyer has calculated that "no variation" will occur again in London about 1973, and it would appear, according to our estimate of the movements, that, about that time, both poles will lie north eastward and south westward, being, to a great extent, the converse of their positions at the previous occurrence of "no variation" in London. The greatest dip (74° 42′) is said to have occurred in London in 1723, at which time both poles appear (as we might express it) to have pointed towards London.

It will be seen, from these reckonings of the relative position of these poles at different times, how exceedingly difficult it is to balance the varying effect of the two magnetic poles in their constantly changing relations to each other. A certain movement of one pole may weaken its power of attraction on the needle at a particular station, but a corresponding movement of the

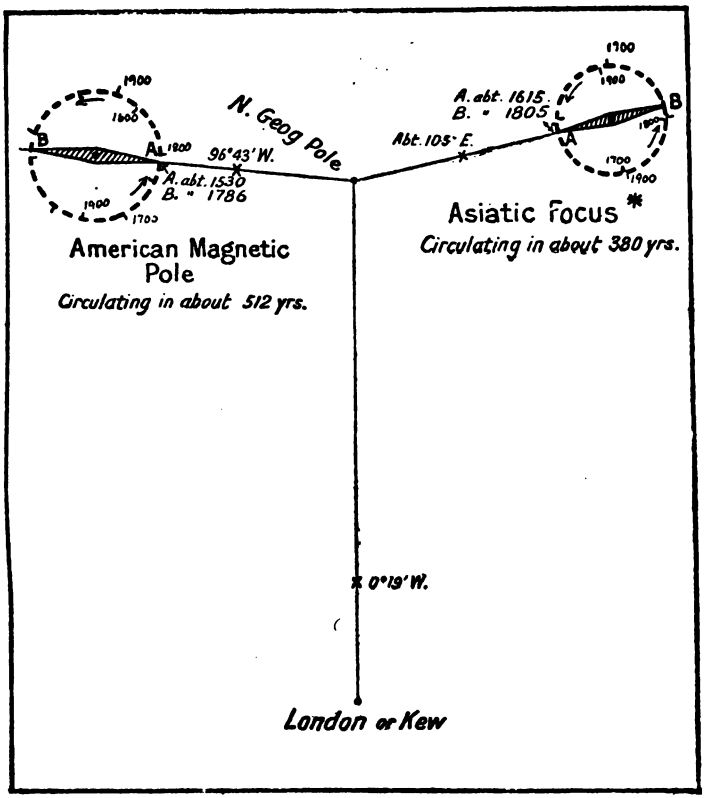

Diagram representing hypothetical circuits of the North Magnetic Pole and the Asiatic Focus, in relation to London, or Kew (51° 28′ N., 0° 19′ W.)

London, or Kew.—Total range of needle, 35° 58′ 25″.

Extreme E.	(11° 20′ E.)	1560	...	...	...	...
No Variation	...	...	1658	...	...	1973
Extreme W.	(24° 38′ 25″ W.)	...	...	1818	...	...
Mean Direction	(6° 9′ W.)	...	1688	...	1944	...

* Note.—In view of the weaker influence of the Asiatic Focus, its circuit is represented by a smaller circle, although there is no reason to suppose that the circuit is actually smaller.

other pole may to a great extent counteract this. The joint effect may be in the direction of neutralizing each other's influence, or, of course, on the other hand, the effect may be cumulative.

The likelihood of there being in the northern hemisphere two magnetic poles exercising an attractive influence on the same end of the magnetic needle, and having different secular periods, is greatly strengthened from the fact that the periods of the secular movement of the needle are so very different in diverse localities. It is difficult to imagine any circumstance which would so satisfactorily explain the difference in these periods as the existence of two poles with different secular motions. The wonderfully small discrepancy between the periods of the secular movement of the needle at the different north American stations is explained by these stations being dominated almost entirely by the North Magnetic Pole. On the other side is Irkutsk, with its short period, dominated by the Asiatic focus. Between these stations lie the various districts where the needle is influenced to a certain extent by both poles.

We can well suppose that in certain positions this double influence may actually have an effect in the direction of shortening the period occupied by the needle in its swing from side to side as, for instance, at Tornea (lat. 65° 51′ N., long. 24° 14′ E.), and Yakutsk (lat. 62° 2′ N., long. 129° 44′ E.), the period in the former being 156 years, and in the latter 150 years. But in most stations the effect must necessarily be to extend the period of the needle's movement to a much greater

length than the period actually occupied by either pole in its secular circuit. Very likely, also, it may follow that ensuing periods will not be exactly the same length, even in the same station, as the poles will not be in exactly the same relation to each other at the succeeding extremes of the same variation, or the succeeding occurrence of no variation. The great complexity connected with the magnetic periods may thus be explained in an intelligible manner.

Owing to the Asiatic focus being much weaker in its influence than the North Magnetic Pole, it may follow that, even in its own immediate neighbourhood, its influence on the needle will not be exclusive of the influence of the latter. At the North Magnetic Pole the needle dips vertically, and, in fact, that pole is distinguished as the pole of verticity. The Asiatic focus, if it influences the *direction* of the needle, must also influence its *dip*; but if the needle is, at the same time, influenced by the other pole, it is to be expected that it will not be able to draw the needle to the vertical position. The possibility of the Asiatic focus having no exclusive influence, may explain how it has not yet been exactly located. It is not improbable that the needle may not be drawn directly towards it, either in declination or dip, and yet that it may exert a far reaching influence. If a magnetic needle is placed between two magnets of unequal strength, it is so influenced by both that it does not point to either, and even if the more powerful magnet is removed to a much greater distance than the other, its influence may still prevent the

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needle from pointing towards the weaker magnet, the divergence being of course proportionate to the distance and strength of the more powerful magnet. It can hardly be doubted that the same rule applies to the terrestrial poles of magnetic attraction.

CHAPTER XIII.

The effect of the unsymmetrical position of the North and South Magnetic Poles on the directive tendency of the magnetic needle.

We have seen that the evidence afforded by the declination returns for many stations in the Northern Hemisphere indicates the existence of two North Magnetic Poles of unequal strength, one of which we have referred to as the North Magnetic Pole, and the other as the Asiatic focus, and that these poles are in all probability not exactly 180 degrees of longitude apart, that is to say they are not symmetrically placed in relation to each other.

It appears indeed to be the rule in nature, rather than the exception, to ignore what we consider symmetry. The most common natural objects are marked by diversity, and the planets, like the stars, differ from one another. The earth itself is not a perfect sphere, and its orbit is not a perfect circle. This want of symmetry might therefore by analogy be reasonably expected.

If we now turn our attention to the Southern Hemisphere, we find that the South Magnetic Pole is unsymmetrically placed in relation to the North Magnetic Pole.

This want of symmetry in the poles of natural magnets is referred to by M. Guillemin, who mentions, that "in natural magnets the points at which attraction takes place, otherwise called *poles*, are *generally* unsymmetrically placed, and depend entirely on the *internal structure* of the magnet, as well as on the *irregularities of its surface*."* The earth, we may take it, is an electro-magnet magnetized by natural causes, and there is no doubt whatever that its poles are unsymmetrically placed. There is some slight discrepancy in the different authorities as to the supposed exact position of the magnetic poles, but the want of symmetry in their supposed positions is a matter of universal agreement, and the amount of the difference of symmetry is also practically agreed upon.

Thus, for instance, the position of the magnetic poles, according to M. Guillemin and the Encyclopædia Britannica, respectively, are as follows:—

	Guillemin.†		Ency. Brit.	
	Latitude.	*Longitude.*	*Latitude.*	*Longitude.*
North Magnetic Pole, ...	70° 5′ N.	96° 45′ W.‡	70° 5′ N.	96° 43′ W.
South do. ...	75° 5′ S.	154° 8′ E.‡	73° 30′ S.	147° 30′ E.

Thus the longitudinal distance between the poles, according to M. Guillemin, is 109° 7′, while, according to the Encyclopædia Britannica, it is 115° 47′,—a very trifling difference in such a matter.

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* *Electricity and Magnetism*, p. 12. † do. p. 81. ‡ Guillemin's figures for longitude are 99° 5′ W., and 151° 48′ E., but as these are evidently based on the meridian of Paris, while those of the Encyclopædia Britannica are of course based on the meridian of Greenwich, 2° 20′ west of Paris, the necessary correction has been made to facilitate comparison.

Let us, as we have hitherto done, accept the figures of the Encyclopædia Britannica. It is evident that if the South Magnetic Pole were longitudinally symmetrical with the North Magnetic Pole, it would be placed exactly 180 degrees of longitude distant from it, and, as the North Magnetic Pole is in longitude 96° 43′ west, this would mean that the South Magnetic Pole would be in longitude 83° 17′ east. If it were so placed, then one end of the needle could longitudinally point to the North Magnetic Pole, and the other end to the South Magnetic Pole at the same time,—that is, of course, disregarding the dip. Instead, however, of being in longitude 83° 17′ east, the South Magnetic Pole is in longitude 147° 30′ east, an excess—or a deficiency, it makes no difference how we regard it—of no less than 64° 13′.

Now, it is evident, seeing that the end of the needle that points towards the south is attracted towards the South Magnetic Pole, or its secondary pole, just as the marked end is attracted towards the North Magnetic Pole, or the Asiatic focus, that this want of longitudinal symmetry in the primary poles must also have an effect in deciding the position of the rigid needle. As the semi-circumference of the earth is 180 degrees of longitude, the *farthest east* position which it is possible to attain in calculating from the longitudinal position of the North Magnetic Pole (96° 43′ west) is 83° 17′ east. Therefore, by the amount of the longitudinal difference of the position of the South Magnetic Pole from that longitude, the south-indicating end of the needle is being

attracted *in the same direction* as the marked end is being attracted. The marked end of the needle is, we have supposed, being drawn by the North Magnetic Pole towards a position in latitude 70° 5′ north, and longitude 96° 43′ west. But the South Magnetic Pole is attracting the south-indicating end of the needle towards a point in latitude 73½ degrees south, on a meridian which may be considered as 64° 13′ *west* of the opposite meridian. By such power as the South Magnetic Pole can exercise, the marked end of the needle must therefore necessarily be deflected; so that in London, for instance, it would not (even apart from the attraction of the Asiatic focus) point to the true position of the North Magnetic Pole, but to the east of it. Great as was the westerly variation in London in 1818, when it attained its maximum, 24° 38′ 25″ W., it was certainly not so great as it would have been had the marked end of the needle actually pointed to the North Magnetic Pole. We can readily by trigonometrical calculation find what the angle of variation at London in 1818 would have been had the needle then actually pointed to the latter. Let us form a triangle,* one side of which represents a line extending from London to the North Geographical Pole, the second side a line from the latter to the North Magnetic Pole, and the third side a line from London to the North Magnetic Pole. Taking the latitude of London as 51½ degrees north, we get the length of the first side of the triangle as 38½ degrees of geographical latitude. The length of the second side—

* See Appendix; No. II.

the line from the North Geographical Pole to the North Magnetic Pole,—will be 19° 55′ of geographical latitude, that being the distance of the magnetic pole from the geographical pole, and the angle contained between these two sides will be 96° 43′. We find that the length of the third side, being the distance from London to the North Magnetic Pole, is equivalent to 44° 40′ of geographical latitude, and we get the angle of variation, being the angle contained between the two sides of the triangle extending from London, as 28° 46′.

The angle of variation at London in 1818 was actually 24° 38′ 25″, and, although the Asiatic focus may have had an influence in reducing the angle, it is quite likely, and is indeed to be expected, that the South Magnetic Pole also had an influence in reducing it.

It will naturally be objected that in a latitude so far north as London, the influence of the South Magnetic Pole could not have had any disturbing effect. Let us then calculate—in the same way as we employed to ascertain the angle of variation which would have occurred had the needle pointed to the North Magnetic Pole—what angle would be produced at London if the needle were attracted to the South Magnetic Pole, and the latter were situated in latitude 73½ degrees south, and longitude 64° 13′ west, that being the amount by which the South Magnetic Pole is unsymmetrically placed longitudinally.

Let us imagine a triangle,* one side of which is a straight line from London to the South Geographical

* See Appendix ; No. III.

Pole, the second side a line from the latter to the South Magnetic Pole, and the third side a line from the South Magnetic Pole to London. Taking the latitude of London as 51½ degrees north, the length of the first side is 141½ degrees of latitude. The length of the second side is 16½ degrees of latitude, and the angle contained between these sides is 64° 13′. We find that the length of the third side of the triangle, being the distance from London to the South Magnetic Pole, would, in our supposititious case, be equivalent to 132° 19′ of geographical latitude, and that the angle of variation—being the angle between the two sides of the triangle meeting at London—is 20° 14′.

Now we may suppose that at the magnetic equator the influence of both poles will be equally felt, so that if the particulars were as stated, and London were situated at the magnetic equator, this angle of 20° 14′ would, through the opposing influence of the North Magnetic Pole in its unsymmetrical position, be neutralized to the extent of one half, resulting in a divergence to the extent of 10° 7′. As London, however, is far north of the magnetic equator, the influence of the North Magnetic Pole will greatly predominate. If we suppose that mid-way between the magnetic equator and the North Magnetic Pole, the disturbing influence of the South Magnetic Pole would be weakened to the extent of about one fourth of its effect at the magnetic equator—the force of magnetic attraction varying inversely as the square of the distance—then, if London were in magnetic latitude 45 degrees north, the disturbing

influence would, on the particulars detailed, be about 2° 32′.

We have found, by the preceding calculation, that with the North Magnetic Pole in latitude 70° 5′ North, and longitude 96° 43′ West, its distance from London would be equivalent to 44° 40′ of geographical latitude. If we assume that these degrees are equivalent to degrees of magnetic latitude, we can, by subtracting that sum from 90 degrees, fix on the magnetic latitude of London in 1818. This would therefore have been 45° 20′ N., which is practically mid-distance from the magnetic equator, so that the disturbing effect of the South Magnetic Pole would, according to our suppositions, evidently be about 2° 32′. Thus the South Magnetic Pole would appear to have an appreciable influence in deciding the position of the needle even in so high a northern latitude as that of London.

There seems to be reason to suppose that the needle points straight towards one or other magnetic pole only when not affected (1) by both primary and secondary poles in the same hemisphere, or (2) by the want of longitudinal symmetry in the magnetic poles in the different hemispheres, or (3) by local causes. It must follow, seeing that the needle must be affected by one or more of these disturbing influences everywhere, except in the immediate neighbourhood of the primary magnetic poles, that in no spot on the whole surface of the earth, excepting in the immediate neighbourhood of either primary magnetic pole, or where induced to do so by local causes, will the magnetic needle point straight

towards either magnetic pole. Doubtless, in the immediate neighbourhood of either pole, such pole's influence will be so powerful as to be, to all intents, absolutely exclusive, and will induce the needle to point straight towards it. Everywhere else, however, there will be a divergence. This source of divergence may, however, be practically ignored as regards stations not very greatly removed from the primary magnetic poles.

CHAPTER XIV.

The effect of the unsymmetrical position of the magnetic poles in deciding the position of the magnetic equator.— Its effect on the lines of magnetic dip.

LET us now consider whether the want of symmetry in the position of the magnetic poles will have any effect on the position of the magnetic equator. We can afterwards consider the Asiatic focus and the corresponding focus in the Southern Hemisphere.

The geographical poles are symmetrically placed, and every portion of the geographical equator is consequently 90 degrees of latitude distant from each of these poles. With the magnetic poles unsymmetrically placed, the same relation cannot exist between the magnetic poles and the magnetic equator.

Let us first confine our attention to the North Magnetic Pole. This pole, according to Ross, is situated in latitude 70° 5′ north, and longitude 96° 43′ west. Let us place the magnetic equator so that every portion of it shall be 90 degrees of latitude distant from that position. In longitude 96° 43′ W., the equator will have to pass through a point 19° 55′ south of the geographical equator, and in longitude 83° 17′ E.—one-half of the circumference of the earth apart from the former point—

it will have to pass through a point 19° 55′ north of the geographical equator. These two points will be the most southerly, and the most northerly touched by this equator. A circle around the earth connecting these two points, and, of course, twice intersecting the geographical equator, would form the magnetic equator in relation to the North Magnetic Pole.*

We now turn to the South Magnetic Pole, which, according to the same authority, is situated in latitude 73½ degrees south, and longitude 147½ degrees east. If we place the magnetic equator so that every portion of it shall be 90 degrees of latitude distant from this pole, we must make a circle surrounding the earth which shall pass through two points in the following positions—(1) 16° 30′ north latitude, and 147° 30′ east longitude; and (2) 16° 30′ south latitude, and 32° 30′ west longitude. These two positions will be respectively the most northerly and the most southerly points touched by this equator, and the equator will of course intersect the geographical equator in two points, each being situated midway between these positions. This circle then will form the magnetic equator in relation to the South Magnetic Pole.*

Now, of course, there cannot be two magnetic equators on the earth, each twice intersecting the geographical equator, and commingling with each other in a somewhat complicated manner, such as would result by the formation of two independent equators in the manner described. It seems likely, however, that the actual magnetic equator is simply a

* See maps facing page 154.

combination of the two suggested magnetic equators, each modified to some extent not only by the influence of the magnetic pole opposite to the pole of its origin, but also by the minor magnetic foci.

The Asiatic focus and the corresponding Southern magnetic focus, being of much weaker attraction than the magnetic poles, may not have great influence in connection with the magnetic equator. Still it is not unlikely that they will have some influence, and that the equator may thereby be deflected northward or southward to some extent, and thus thrown somewhat out of the position which it would occupy were its position decided merely by the two primary poles.

As has been pointed out in chapter IV., there is some uncertainty as to the exact position of the magnetic equator, and even as to its intersections of the geographical equator. Such an eminent authority as M. Guillemin states that it intersects the geographical equator in four points, while other authorities are of opinion that it intersects it only twice. The explanation here suggested, that the magnetic equator is in reality a combination of two equators formed by the opposing influence of the two magnetic poles in their unsymmetrical positions, as modified by the influence of the magnetic focus in Asia and corresponding focus in the Southern Hemisphere, would go to show how such uncertainty may have arisen. In this way, we could readily account for there being, as M. Guillemin asserts, no less than four intersections of the geographical equator. At the same time, owing to the comparative

weakness of the magnetism in each hemisphere during its winter season, the intersections, having reference to the magnetic pole in such hemisphere, might be overcome by the prevailing influence of the magnetic pole in the hemisphere more strongly magnetized. Thus it might only be when the magnetism of each hemisphere was nearly equal, as at the equinoxes, that it might occur that the magnetic equator intersected the geographical equator in four points, so that in the ordinary case there would be only two points of intersection.

We have noticed that the farthest north portion of a magnetic equator in relation to the North Magnetic Pole alone, would be situated about longitude 83° 17 'E., while the farthest north portion of a magnetic equator, in relation to the South Magnetic Pole alone, would be situated about longitude 147° 30′ E. If we take the mean of these positions we should get an approximation to the longitude of the farthest north portion of the actual magnetic equator, which would therefore be about 115° 23½′ E. In the same manner, the farthest south portion of the actual magnetic equator should be in the neighbourhood of the mean between longitude 96° 43′ W. and 32° 30′ W., which is longitude 64° 36½ W. Judging by the map shewing the position of the magnetic equator, prepared from the observations of the late Sir F. Evans, the most northerly and the most southerly portions of the magnetic equator are, in reality, not far removed from these longitudes. These positions one would expect to be subject to some alteration through the varying influence of the poles in

the changing seasons, as well as through the influence of the Asiatic focus, in the Northern Hemisphere, and corresponding southern focus.

The geographical position of the magnetic equator must also, no doubt, be influenced to a slight extent by the diurnal changes in the earth's magnetism, occasioned by the daily rotation. Just as the magnetic poles, or points of primary attraction in these poles, describe a small daily circuit, the magnetic equator will probably make a corresponding small northward and southward movement, proportionate to the daily circuit of the magnetic poles. Such a movement northward and southward would, of course, increase the difficulty of accurately fixing the position of the magnetic equátor.

Just as the geographical equator may be described as the principal parallel of geographical latitude, so we may regard the magnetic equator as the principal "parallel" of magnetic latitude. The remaining curves of magnetic latitude will lie on either side of the magnetic equator, and occupy the space between it and the respective magnetic poles. We have seen that there is reason to suppose that the actual magnetic equator is really a modified combination of two magnetic equators, one having reference to each magnetic pole, and its position being influenced to some extent by the Asiatic and Southern foci. We may, therefore, conjecture that the remaining magnetic curves will be a combination of the same opposing influences. But as the influence of the southern magnetic pole and focus becomes gradually weaker as we pass northward from the magnetic

equator, so the influence of the northern magnetic pole and the Asiatic focus becomes gradually stronger, and the converse must be the case in the Southern Hemisphere. Thus, in the immediate neighbourhood of each magnetic pole, the curve of magnetic latitude would have much more resemblance to a true circle than it would have farther away. Let us look at the North Magnetic Pole alone for a moment. We have seen that the magnetic equator relating to it alone would be a circle around the earth, every part of which would be separated from the magnetic pole by 90 degrees of latitude. So the magnetic "parallels" relating to this pole alone would be concentric circles around the magnetic pole, covering the distance between it and the equator.

If we regard the South Magnetic Pole alone, exactly the same description of the magnetic "parallels" relating to that pole, and the corresponding magnetic equator would apply.

We have seen, however, that the influence of each magnetic pole is not annihilated at the magnetic equator. We have found that the magnetic equator itself is probably the result—as affected to some extent by the influence of the Asiatic and Southern foci—of a combination of the two circles, which we have imagined at a distance of 90 degrees of latitude from each magnetic pole respectively. Therefore, we may suppose, that the curves of magnetic latitude will also be decided by the same opposing influences.

In the Northern Hemisphere, the influence of the

North Magnetic Pole predominates, and is, in its own immediate neighbourhood, probably practically exclusive of the influence of both the Asiatic focus and the South Magnetic Pole. If this is so, then the curve indicating magnetic latitude 89 degrees north, may be a true circle, or nearly so. As we travel southward from the North Magnetic Pole, the influence of the South Magnetic Pole in its unsymmetrical position gradually becomes apparent, as well as—at any rate in one direction—the influence of the Asiatic focus, and the curve of magnetic latitude is no longer a circle, but a combination of the opposing influences. The likeness to a circle gradually becomes less and less, till at last we reach the magnetic equator, where the influence of each pole is equally balanced, and the curious combination intersecting the geographical equator is the natural result.

These curves of magnetic latitude,—which cannot properly be called "parallels," seeing that they are by no means parallel with each other—are the lines indicating equal magnetic dip. At the magnetic equator, where the influence of one magnetic pole is exactly balanced by the influence of the other, there is no dip, but as we move away from the magnetic equator northward or southward, the dip becomes apparent, and gradually increases, until at the magnetic poles it reaches 90 degrees.

CHAPTER XV.

The hourly changes in declination, at various stations in the Northern Hemisphere considered in connection with the supposition of a daily rotatory displacement of the North Magnetic Pole or its centre of primary attraction.

THE table on page 118 of hourly changes (local time) in the declination and dip of the magnetic needle is compiled from two tables which appear in the last edition of the Encyclopædia Britannica. In the changes in declination, the *plus* sign indicates a movement to the west, and the *minus* sign a movement to the east. In the changes in inclination, *plus* indicates an increase, and *minus* a decrease in the angle of dip. The letter "q" above a column signifies that the particulars given are the mean of a few specially selected *quiet*, or normal, days in each month; while the letter "a" similiarly signifies that the particulars given are the mean movement according to the observations of *all* days, unless, indeed, when very exceptional magnetic disturbances occur. A second table has been added, containing the same figures rearranged—in the case of Jan Mayen proportionally modified—to show approximately the nature of the movements taking place *simultaneously* at the various stations; the Kew time can, of course, be altered to the corresponding time of any other meridian.

The local time at the North Magnetic Pole has also been added to show its position with reference to the sun.

Let us now consider to what extent the particulars given in the table harmonize with the supposition of a daily rotatory displacement of the pole or of the centre of primary attraction. We have suggested that the movement of the needle in declination actually signifies a corresponding movement of the magnetic pole (or centre of primary attraction) in relation to the place of observation, and that the movement of the needle in dip indicates by an increase in the angle of dip the approach of the pole (or centre of primary attraction in the pole) somewhat nearer to the place of observation, and by a decrease of the angle a corresponding recession. In this enquiry we must, to begin with, assume that the movements of the needle at each of the specified stations are primarily influenced by the North Magnetic Pole. If this is really the case, then, even though, as there appears to be reason to suppose, the directive tendency of the needle may not, at any of these stations, be directly towards the North Magnetic Pole, the movements of the needle should, at each of them, approximately coincide with the movements at that pole.

To enable us to follow the hypothetical daily movement, let us take it that the movement is circular, and let us represent the circuit by a dial, numbered around the margin from 1 to 24, to correspond with the twenty-four hours of the solar day. Let us for the sake of simplicity, to start with, as we have nothing to go upon in fixing the position of the figures on the dial, place

MEAN DIURNAL INEQUALITY OF WESTERLY DECLINATION, ALSO OF INCLINATION. I.—FOR LOCAL TIME.

Station & Epoch.	Jan Mayen. 71° 0′ N. 8° 28′ W. 1882-83.				Kew. 51°28′ N. 0°19′W. 1890-94.*		Paris. 48° 49′ N. 2° 29′ E. 1883-97.		St. Petersburg. 59° 41′ N. 30° 29′ E. 1873-85.				Tiflis. 41°43′N. 44°48′E. 1893-96.		*Station & Epoch.*
Astron. Hrs	*Declin.*		*Inclin.*		*Declin.*	*Inclin.*	*Declin.*	*Inclin.*	*Declin.*		*Inclin.*		*Declin.*	*Inclin.*	*Astron. Hrs*
Local Time.	*a.*	*q.*	*a.*	*q.*	*q.*	*q.*	*a.*	*a.*	*a.*	*q.*	*a.*	*q.*	*a.*	*a.*	*Local Time.*
	′	′	′	′	′	′	′	′	′	′	′	′	′	′	
0- 1	+ 3·7	+7·3	−4·5	−0·2	+5·3	+0·4	+5·3	+0·2	+4·6	+4·3	+0·7	+0·7	+3·6	−0·7	0- 1
1- 2	6·4	7·1	5·6	1·2	4·9	0·2	4·9	0·2	4·9	4·5	0·4	0·4	3·5	0·6	1- 2
2- 3	7·4	5·9	6·3	2·2	3·6	+0·0	3·7	0·2	4·1	3·6	0·2	+0·1	2·7	−0·3	2- 3
3- 4	8·5	4·3	6·1	2·9	2·0	−0·1	2·3	0·2	2·7	2·3	+0·0	−0·1	1·7	+0·1	3- 4
4- 5	10·6	3·0	5·1	3·2	0·8	0·3	1·1	0·1	1·5	1·3	−0·1	0·3	0·8	0·4	4- 5
5- 6	14·2	2·3	3·1	2·9	+0·2	0·4	+0·2	+0·0	0·6	0·7	0·2	0·3	0·3	0·6	5- 6
6- 7	15·2	2·2	−1·7	2·2	−0·1	0·6	−0·4	−0·2	+0·0	0·4	0·3	0·4	+0·1	0·5	6- 7
7- 8	15·8	2·6	+0·3	1·3	0·4	0·6	0·9	0·3	−0·4	0·2	0·3	0·5	−0·1	0·3	7- 8
8- 9	13·2	2·6	2·0	−0·3	0·6	0·6	1·3	0·3	1·0	+0·0	0·4	0·6	0·4	0·1	8- 9
9-10	7·4	2·0	2·5	+0·5	0·7	0·5	1·5	0·3	1·4	−0·2	0·5	0·6	0·7	0·0	9-10
10-11	+ 1·1	+0·5	3·0	1·0	0·9	0·5	1·6	0·3	1·6	0·4	0·5	0·6	0·8	+0·0	10-11
11-12	− 3·6	−1·8	4·0	1·3	1·1	0·4	1·6	0·3	1·5	0·6	0·5	0·4	0·8	−0·1	11-12
12-13	6·6	4·2	4·6	1·5	1·0	0·3	1·4	0·3	1·3	0·7	0·5	0·3	0·8	0·1	12-13
13-14	10·5	6·4	5·0	1·6	1·0	0·3	1·2	0·3	1·2	0·8	0·5	0·3	0·7	0·1	13-14
14-15	15·2	7·8	5·6	1·6	1·1	0·3	1·2	0·3	1·2	1·0	0·5	0·3	0·7	0·2	14-15
15-16	16·9	8·4	5·0	1·5	1·5	0·2	1·2	0·4	1·4	1·3	0·4	0·3	0·6	0·2	15-16
16-17	17·0	8·1	4·2	1·4	2·0	0·2	1·6	0·4	1·7	1·8	0·5	0.3	0·8	0·2	16-17
17-18	13·7	7·0	2·4	1·2	2·5	−0·1	1·9	0·3	1·9	2·3	0·4	0·3	1·4	0·1	17-18
18-19	9·3	5·1	+0·7	0·9	3·1	+0·2	2·4	−0·0	2·2	2·8	−0·2	−0·1	2·1	−0·0	18-19
19-20	6·8	3·2	−0·1	0·8	3·4	0·6	2·7	+0·4	2·5	3·2	+0·1	+0·3	2·8	+0·3	19-20
20-21	3·7	−0·6	0·7	0·8	2·8	1·0	2·3	0·7	2·3	3·0	0·6	0·6	2·6	0·5	20-21
21-22	2·4	+2·1	1·2	0·9	−0·8	1·3	−0·5	0·9	−1·0	−1·7	1·0	1·0	−1·1	+0·4	21-22
22-23	− 0·5	4·6	2·2	0·8	+1·8	1·2	+2·0	0·7	+1·0	+0·4	1·2	1·2	+0·9	−0·1	22-23
23- 0	+ 2·5	+6·5	−3·4	+0·4	+4.3	+0·8	+4·2	+0·4	+3·1	+2·7	+1·1	+1·1	+2·7	−0·5	23-24

NOTE.—Plus (+) or Minus (−) will be understood as applying between corresponding signs though not shown.
* The Epoch for the *Inclination* at Kew is 1891-95

MEAN DIURNAL INEQUALITY OF DECLINATION AND INCLINATION. II.

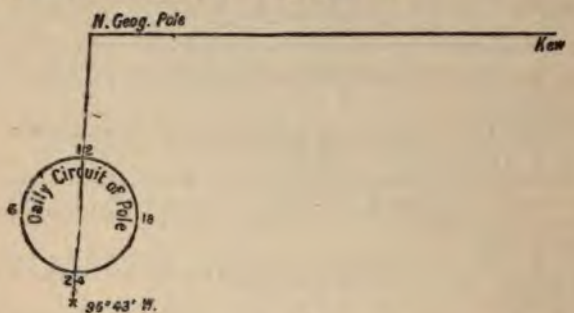
Showing (approximately) the *simultaneous* movement of the needle at each station, in Kew time, and in that at the North Magnetic Pole (N) and Asiatic Focus (A) (in, say, long. 110E.). The Jan Mayen figures have been proportionately altered (approximately).

Station and Epoch.			Jan Mayen. 71° 0′ N. 8° 28′ W. 1882-83.				Kew. 51° 28′ N. 0°19′W. 1890-94.*		Paris. 48° 49′ N. 2° 29′ E. 1883-97.		St. Petersburg. 59° 41′ N. 30° 29′ E. 1873-85.				Tiflis. 41°43′ N. 44°48′E. 1893-96.	
Astron. Hours, at—			*Declin.*		*Inclin.*		*Declin.*	*Inclin.*	*Declin.*	*Inclin.*	*Declin.*		*Inclin.*		*Declin.*	*Inclin.*
N.	Kew.	A.	*a.*	*q.*	*a.*	*q.*	*q.*	*q.*	*a.*	*a.*	*a.*	*q.*	*a.*	*q.*	*a.*	*a.*
			′	′	′	′	′	′	′	′	′	′	′	′	′	′
18	0- 1	7	+ 3·1	+6·9	−4·0	+0·1	+5·3	+0·4	+5·3	+0·2	+4·1	+3·6	+0·2	+0·1	+1·7	+0·1
19	1- 2	8	5·1	7·2	5·1	−0·7	4·9	0·2	4·9	0·2	2·7	2·3	+0·0	−0·1	0·8	0·4
20	2- 3	9	6·9	6·5	6·0	1·7	3·6	+0·0	3·7	0·2	1·5	1·3	−0·1	0·3	0·3	0·6
21	3- 4	10	8·0	5·1	6·2	2·6	2·0	−0·1	2·3	0·2	0·6	0·7	0·2	0·3	+0·1	0·5
22	4- 5	11	9·6	3·7	5·6	3·1	0·8	0·3	1·1	0·1	+0·0	0·4	0·3	0·4	−0·1	0·3
23	5- 6	12	12·4	2·7	4·1	3·1	+0·2	0·4	+0·2	+0·0	−0·4	0·2	0·3	0·5	0·4	0·1
0	6- 7	13	14·7	2·3	2·4	2·6	−0·1	0·6	−0·4	−0·2	1·0	+0·0	0·4	0·6	0·7	0·0
1	7- 8	14	15·5	2·4	−0·7	1·8	0·4	0·6	0·9	0·3	1·4	−0·2	0·5	0·6	0·8	+0·0
2	8- 9	15	14·5	2·6	+1·2	−0·8	0·6	0·6	1·3	0·3	1·6	0·4	0·5	0·6	0·8	−0·1
3	9-10	16	10·3	2·3	2·3	+0·1	0·7	0·5	1·5	0·3	1·5	0·6	0·5	0·4	0·8	0·1
4	10-11	17	+ 4·3	+1·3	2·8	0·8	0·9	0·5	1·6	0·3	1·3	0·7	0·5	0·3	0·7	0·1
5	11-12	18	− 1·2	−0·6	3·5	1·2	1·1	0·4	1·6	0·3	1·2	0·8	0·5	0·3	0·7	0·2
6	12-13	19	5·1	3·0	4·3	1·4	1·0	0·3	1·4	0·3	1·2	1·0	0·5	0·3	0·6	0·2
7	13-14	20	8·6	5·3	4·8	1·6	1·0	0·3	1·2	0·3	1·4	1·3	0·4	0·3	0·8	0·2
8	14-15	21	12·9	7·1	5·3	1·6	1·1	0·3	1·2	0·3	1·7	1·8	0·5	0.3	1·4	0·1
9	15-16	22	16·1	8·1	5·3	1·6	1·5	0·2	1·2	0·4	1·9	2·3	0·4	0·3	2·1	−0·0
10	16-17	23	17·0	8·3	4·6	1·5	2·0	0·2	1·6	0·4	2·2	2·8	−0·2	−0·1	2·8	+0·3
11	17-18	0	15·4	7·6	3·3	1·3	2·5	−0·1	1·9	0·3	2·5	3·2	+0·1	+0·3	2·6	0·5
12	18-19	1	11·5	6·1	1·6	1·1	3·1	+0·2	2·4	−0·0	2·3	3·0	0·6	0·6	−1·1	+0·4
13	19-20	2	8·1	4·2	+0·3	0·9	3·4	0·6	2·7	+0·4	−1·0	−1·7	1·0	1·0	+0·9	−0·1
14	20-21	3	5·3	−1·9	−0·4	0·8	2·8	1·0	2·3	0·7	+1·0	+0·4	1·2	1·2	2·7	0·5
15	21-22	4	3·1	+0·7	1·0	0·9	−0·8	1·3	−0·5	0·9	3·1	2·7	1·1	1·1	3·6	0·7
16	22-23	5	− 1·5	3·4	1·7	0·9	+1·8	1·2	+2·0	0·7	4·6	4·3	0·7	0·7	3·5	0·6
17	23- 0	6	+ 1·0	+5·6	−2·8	+0·6	+4.3	+0·8	+4·2	+0·4	+4·9	+4·5	+0·4	+0·4	+2·7	−0·3

NOTE.—Plus (+) or Minus (−) will be understood as applying between corresponding signs though not shown.
* The Epoch for the *Inclination* at Kew is 1891-95.

the figure 12 nearest to the geographical North Pole.

Any necessary correction in the placing of the figures can be carried out after we shall have seen how this preliminary arrangement fits in with the actual movements of the needle. The figure 24 will therefore be at the most southern part of the circuit, from which point the numbers will run consecutively, clock-wise around the dial. The figure 1 will consequently be slightly to the west and north of the figure 24, and the figure 13 slightly to the east and south of the figure 12. The dial may be imagined as lying on its back on the earth, with the figures facing upwards.



Let us now suppose that the hours on the dial correspond with Greenwich time. Thus, when the magnetic pole, or the centre of primary attraction in the pole, is at the most southern part of its daily circuit, the time in Greenwich will be 24, that is to say 12 o'clock midnight; and when the magnetic pole is at the most northern part of its daily circuit, the time in Greenwich will be 12 o'clock noon.

It is necessary to change the local time at each of the stations to the equivalent in Greenwich time, so as to reduce the observations to one basis. Taking the longitude of each place as given in the table, we find that when it is 12 o'clock noon at Greenwich, it is in Jan Mayen 11.26 a.m.; in St. Petersburg 2.2 p.m.; in Kew 11.59 a.m.; in Paris 12.10 p.m.; and in Tiflis 2.59 p.m.

Let us first deal with the movements in declination, for which purpose we may take the time of the commencement of the increase in the westerly declination, that being one of the most conspicuous of the daily movements. Judging, as nearly as we can from the table, the actual time of the commencement of this movement, and noting the Greenwich equivalent in time, we get the following:—

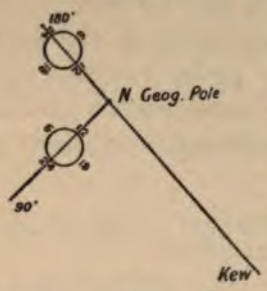
MEAN DAILY TIME OF COMMENCEMENT OF INCREASE IN WESTERLY DECLINATION.

	Jan Mayen.	*Kew.*	*Paris.*	*St. P't'rsb'g.*	*Tiflis.*
As estimated from table of daily movement, in local time, ...	8.45 a.m.	9.50 a.m.	9.40 a.m.	10.25 a.m.	10.15 a.m
Corresponding time at Greenwich, ...	9.19 a.m.	9.51 a.m.	9.30 a.m.	8.23 a.m.	7.16 a.m.

In all cases we have, when available, taken the time from the "quiet-day" returns, as these returns are, of course, the most suitable for furnishing information as to the actual normal movement at the pole. For Paris and Tiflis this information is not available, and we have therefore, been obliged for these stations to take the "all-day" returns. In regard to the declination, however, there is not, so far as can be judged from the figures for the other stations, any great discrepancy

between the time of commencement of the increasing westerly variation in "quiet-day" and "all-day" figures. We have now to consider what will be the position of the magnetic pole, or its centre of primary attraction, on the dial which we are supposing to represent its daily movement, when it will first begin to move to the west in relation to each of these stations.

Let us for a moment imagine the magnetic pole to be situated geographically on the same meridian as Kew.



It is evident that with the figures on the dial placed as specified — that is with the figure 12 nearest to the North Geographical Pole, and the figure 24 at the most southern part of the circuit—the magnetic pole, or its centre of primary attraction, would in relation to Kew commence to move to the west as it passed over the figure 18. Similarly with the magnetic pole on the meridian 180 degrees away from Kew, the movement towards the west would, in relation to Kew, commence as the pole, or its centre of primary attraction, passed over the figure 6 on the daily circuit. With the pole 90 degrees to the west of Kew, the westerly movement would commence at the figure 12 on the circuit, and with the pole 90 degrees to the east of Kew, at the figure 24 on the circuit. If this is the case for Kew, it must also be the case for each of the other stations, whether geographically they are situated

north or south of the assumed latitude of the magnetic pole.

On this basis we can, as we know the geographical position of each of the stations mentioned, readily calculate the position of the magnetic pole, or its centre of primary attraction, on the daily circuit, when the westerly movement should commence. We have merely to take the longitude of each station in relation to the longitude of the magnetic pole, and divide the space between the figures in the daily circuit, in proportion to the longitudinal distance of the pole from the observing station.

The longitude of Jan Mayen is 8° 28′ west, and of the magnetic pole 96° 43′ west. The magnetic pole is thus 88° 15′ west of Jan Mayen; that is 1° 45′ less than 90 degrees. It is evident, therefore, that, on the suppositions we have made, the westerly movement will commence with the pole between the figures 18 and 12. Taking a westerly movement of 90 degrees as representing a change of position, on the dial, of six hours, a westerly movement of 88° 15′ will represent a change of position of about 5 hours 53 minutes Thus, the westerly movement of the needle at Jan Mayen should commence when the magnetic pole, or the centre of primary attraction, is removed by that distance, on the dial, from the figure 18, in the direction of the figure 12. This would make the position on the dial 12 hours 7 minutes, and, as we are supposing the hours on the dial to coincide with Greenwich time, the westerly movement at Jan Mayen should thus commence about 12.7 p.m.

If we work out the time of commencement of the westerly movement in the same manner for each of the other stations, we find that the position on the dial, when this movement commences, will be for each of these stations as follows:—Kew, 11.34; Paris, 11.23; St. Petersburg, 9.31; and Tiflis, 8.34; and, as we have just stated, we are supposing these hours to correspond with Greenwich time.

The following Table shows how this result compares with the hours as estimated from the table of diurnal movement:—

MEAN DAILY TIME OF COMMENCEMENT OF INCREASE IN WESTERLY DECLINATION.

	Jan Mayen.	*Kew.*	*Paris.*	*St. P't'rsb'g.*	*Tiflis.*
As estimated from table of daily movement, in local time, ...	8.45 a.m.	9.50 a.m.	9.40 a.m.	10.25 a.m.	10.15 a.m
Corresponding time at Greenwich, ...	9.19 a.m.	9.51 a.m.	9.30 a.m.	8.23 a.m.	7.16 a.m.
Time found on basis of movement of magnetic pole, or centre of primary attraction.	12.7 a.m.	11.34 a.m.	11.23 a.m.	9.31 a.m.	8.34 a.m.
Difference of calculated from estimated time.	+ 2h 48m	+ 1hr 43m	+ 1hr 53m	+ 1hr 8m	+ 1hr 18m

If now we change the position of the dial so that instead of the figure 12 we have the figure 10 nearest to the Geographical Pole, it is evident that each of the times found would be made two hours earlier, which would make the results as follows:—

	Jan Mayen.	*Kew.*	*Paris.*	*St. P't'rsb'g.*	*Tiflis.*
Greenwich equivalent of estimated time, ...	9.19 a.m.	9.51 a.m.	9.30 a.m.	8.23 am.	7.16 a.m.
Calculated time, ...	10.7 a.m.	9.34 a.m.	9.23 a.m.	7.31 a.m.	6.34 a.m.
Difference, ...	+ 48 m.	− 17 m.	− 7 m.	− 52 m.	− 42 m.

It is rather interesting to notice that the difference between the time of the commencement of the westerly movement, as estimated from the table of diurnal change, and the time as calculated in this way from the conjectured movement of the magnetic pole, or its centre of primary attraction in no case amounts to as much as one hour. For Jan Mayen, however, the time found is considerably later than the time estimated in the table, while for each of the other stations it is earlier.

The approximation of the times estimated to the times calculated is noticeable, and seems to indicate that the primary cause of the daily westward movement of the needle is such as we have suggested. Of course, however, a disturbing factor, the weight of which we cannot accurately reckon, is the Asiatic focus, and the varying influence of that focus, according to the position of each station, is probably the chief cause of the discrepancies between the different stations. It seems probable that this is also the explanation of the want of constancy in the daily movement of the needle at some stations in the Northern Hemisphere, such as is shown in the table of the hourly movement during the summer months at Trivandrum given in Chapter VI.

CHAPTER XVI.

The hourly changes in Dip at various stations in the Northern Hemisphere, considered in connection with the supposition of a daily rotatory displacement of the North Magnetic Pole or its centre of primary attraction.

We shall now deal with the table of diurnal movement, given in the preceding chapter, in connection specially with the changes in dip, and see whether these changes are in agreement with such a daily displacement of the magnetic pole, or its centre of primary attraction, as we have supposed.

There is much more difficulty in dealing with the daily fluctuation in dip than with the changes in declination. Our conjecture is that the dip is greatest when the magnetic pole, or its centre of primary attraction, in its daily circuit is actually at its nearest distance to the place of observation; that the dip increases with the approach, and decreases with the recession.

So far as can be estimated from the table of diurnal movement, the time of the greatest dip, and the equivalent in Greenwich time, for the various stations with which we are dealing, is as follows:— In every case, where possible, the estimate is based on the "quiet-day" observations.

MEAN DAILY TIME OF OCCURRENCE OF GREATEST DIP.

	Jan Mayen.	*Kew.*	*Paris.*	*St. P'tr'sb'g.*	*Tiflis.*
As estimated from the diurnal table, ...	12.15 p.m.	2.30 p.m.	5.30 p.m.	3 p.m.	10 p.m.
Equivalent in Greenwich time, ...	12.49 p.m.	2.31 p.m.	5.20 p.m.	12.58 p.m.	7.0 p.m.

Let us now, in view of the correction made after our preceding calculations in the placing of the figures on the dial representing the daily circuit, suppose the daily movement of the magnetic pole, or its centre of primary attraction, to be represented by a dial with the figure 10 nearest to the Geographical Pole, and the figure 22 at the most southern part.

As the geographical latitude of Jan Mayen is higher than that of the magnetic pole, it would appear to follow that if the latter were on the meridian of Jan Mayen, or on the opposite meridian, the nearest part of the daily circuit to Jan Mayen would, in either case, be the most northern part of the circuit. If the magnetic pole is imagined to be moving westwards from Jan Mayen, it is evident that the part of the daily circuit nearest to Jan Mayen would move from the figure 10 towards the larger figures, and similarly if the magnetic pole is imagined as moving westwards from the meridian 180 degrees from Jan Mayen, it is clear that the nearest point in the daily circuit would move from the figure 10 towards the smaller figures. We are supposing the figure 10 to be always the part nearest to the North Geographical Pole.

Let us now endeavour to calculate what the nearest part to Jan Mayen would be with the magnetic pole

90° west of Jan Mayen. We may make a triangle* of which the angles shall stand for Jan Mayen, the North Magnetic Pole, and the North Geographical Pole. As Jan Mayen is in latitude 71 degrees north, the length of the side extending from there to the North Geographical Pole will be 19 degrees of Geographical latitude, and as the magnetic pole is—as we have assumed—in latitude 70° 5′ north, the side extending from the North Geographical Pole to the North Magnetic Pole will be 19° 55′ of geographical latitude. As we are supposing the North Magnetic Pole to be 90° west of Jan Mayen, the angle at the North Geographical Pole will be a right angle.

We have to find the angle at the North Magnetic Pole, and as the line from the geographical to the magnetic pole passes through the figure 10 on the daily circuit, this angle will be the amount by which the nearest part of the circuit in the position specified is removed from the figure 10. With the magnetic pole 90° west of Jan Mayen, this separation from the figure 10 must be in the direction of the larger figures, and as an angular separation of 90 degrees would bring us to the figure 16, a smaller angle will give a proportionately smaller separation in the direction of the figure 16.

We find that the angle is 45° 18′, so that the part on daily circuit nearest to Jan Mayen, with the magnetic pole in the position specified, is separated from 10 by about 3h. 1m., showing that the nearest part of the circuit would be 13h. 1m.

* See Appendix; No. IV.

With the magnetic pole in longitude 96° 43′ west, and Jan Mayen in longitude 8° 28′ west, the pole is 88° 15′ west of Jan Mayen, being 1° 45′ less than 90 degrees. We have now, therefore, simply to take the proportion which 88° 15′ bears to 90 degrees, assuming the latter to represent a movement on the dial of 3h. 1m., being the space between 10h. and 13h.1m. The proportion is about 2 hours 57 minutes which, therefore, represents the space by which the nearest part of the daily circuit, in the position specified, is separated from 10 in the direction of the larger figures The part is therefore 12h. 57m., which corresponds with 12.57 p.m. Our estimate, from the table of diurnal movement, of the time of the occurrence of the greatest dip in Jan Mayen is 12.49 p.m., so that our calculation of 12.57 p.m. is almost exactly correct.

As the other four stations all lie considerably to the south of the magnetic pole, one would suppose that if the daily movement is circular, the nearest part of the dial would entirely depend on the longitude of the magnetic pole in relation to the longitude of the place of observation, that any part of the circumference of the dial might be nearest according as the relative longitude changes. Thus, with the pole on the same meridian as the place of observation, the nearest part will be 22. With it on the opposite meridian, the nearest part will be 10. As we move eastward from the pole, the nearest part will be removed from 22 up the eastern side of the circuit, and as we move eastward from the opposite meridian, the nearest part will

be removed from 10 down the western side of the circuit.

Assuming this to be so, we can now, in the same way as we have done in the case of Jan Mayen, calculate trigonometrically and proportionally, what is the nearest part of the circuit to St. Petersburg, and to Kew, with the magnetic pole in latitude 70° 5′ north, and longitude 96° 43′ west.* We find in this way, that, in relation to St. Petersburg, the nearest part is 12.20, and in relation to Kew 14.8, corresponding in Greenwich time to 12.20 p.m., and 2h. 8m. p.m. respectively. For these stations, the times estimated from the table of diurnal movement are 12.58 p.m., and 2.31 p.m. respectively.

The difference for Kew is thus 23m. and for St. Petersburg 38m., both calculations being earlier than the estimate.

We have still to deal with Paris and Tiflis, but in neither case, can a proper calculation for comparison with the other stations be made. For both Paris and Tiflis, the information as to the daily fluctuation in the dip is for the "all-day" mean, and, as has been mentioned, it would appear that there is a greater uncertainty as to the relation between the "all-day" and the "quiet-day" changes in dip than in declination. We have the double return for Jan Mayen and for St. Petersburg. In the former, there is a difference of fully five hours between the time of maximum dip as shewn in the "all-day" returns, and the time shewn in the "quiet-day"

* See Appendix; No. IV.

returns. In St. Petersburg, on the other hand, the time in both returns is very similar, the difference being apparently only about half-an-hour. Again, for Jan Mayen, the time of maximum dip is later in the "quiet-day" than in the "all-day" returns, while the reverse is the case in St. Petersburg.

Now, it is to be expected that there is not a very great difference between the time of maximum dip in Paris and in Kew. All the information available in connection with the other movements of the needle points in this direction. It is therefore most probable that if we had a table of the daily movement in dip for both places, of the same character—that is to say either for "quiet days" or "all days"—the movement would be found to be not dissimilar. Unfortunately, however, the table for Kew is for "quiet days" only, and the table for Paris for "all days" only, so that no comparison is possible. This being so, we find that the greatest dip in Paris, on the "all day" mean, occurs about 5.20 p.m., while for Kew, on the "quiet day" mean, the maximum dip is about 2.31 p.m., the Paris maximum being thus about 2h. 49m. later than the maximum at Kew. It can scarcely be doubted that this great difference is occasioned chiefly by the different character of the statement. This being so, it seems to be useless to base any calculation on the Paris returns. It is, of course, manifest that with the magnetic pole in the position specified, and the movement as described, the hour of its nearest approach to Paris would not differ to any great extent from the hour of its nearest

approach to Kew. The hour brought out by a similar calculation is 2.7 p.m., which is one minute earlier than the hour brought out for Kew, and is no less than 3h. 13m. earlier than the time of maximum dip in Paris as estimated from the "all-day" table. Owing to the uncertainty as to the difference between this table and the "quiet day" table, this calculation is of no value.

This leaves only Tiflis to be considered, and for this station also the table applies only to the mean of "all day" observations, so that any calculation as to the hour of maximum dip would be of very little value. In one important respect, however, Tiflis differs from all the other stations, and that is that there only the dip shows a double maximum. We have a maximum at about 7 p.m. in Greenwich time, and an increase in dip of less extent which culminates about 7.15 a.m., these two maxima being thus separated by about 12 hours. It can scarcely be supposed that this double movement is a result of the "all-day" as distinguished from the "quiet day" returns. Tiflis is in longitude 44° 48′ east, and, no doubt, the Asiatic focus will there have considerable effect. It therefore appears likely that the double movement must be a result of the needle being partly influenced in its daily change by both the North Magnetic Pole and the Asiatic focus.

Leaving Paris and Tiflis out of account in view of the uncertainty as to the data, the following is a comparison between the times of greatest dip as estimated from the table of diurnal movement, and as

calculated from the conjectured daily movement of the magnetic pole, or its centre of primary attraction.

MEAN DAILY TIME OF OCCURRENCE OF GREATEST DIP.

	Jan Mayen.	*S. Petersburg.*	*Kew.*
As estimated from diurnal table in Greenwich time.	12.49 p.m.	12.58 p.m.	2.31 p.m.
As calculated from the conjectured daily movement of the magnetic pole, or its centre of primary attraction.	12.57 p.m.	12.20 p.m.	2.8 p.m.
Difference of calculated from estimated time,	+ 8 m.	− 38 m.	− 23 m.

In our calculations in connection with both declination and dip, the mean error for these three stations is comparatively small, and although the information on which the calculations are based is rather limited, and the stations are within a somewhat restricted area, the results arrived at appear to afford ground for supposing that the magnetic poles, or at least their centres of primary attraction, do actually describe a daily circuit, and that the needle at these stations is, at present, or any rate was, at the date of these records, mainly influenced in its daily movement by the attraction of the North Magnetic Pole.

CHAPTER XVII.

The lines of "no declination," or agonic lines.

It appears to be generally agreed that the power which influences the magnetic needle is a power which attracts to the magnetic poles—that, in the same way as steel is attracted by the poles of an ordinary artificial magnet, the magnetic needle is attracted by the poles of this great natural magnet—the earth. Now, we know, that in regard to the *dip* of the needle, the pole has full and complete effect only when it is actually reached. When we arrive at the magnetic pole — and not till then—the dipping needle points straight downwards. At the magnetic equator, the dipping needle remains perfectly horizontal, as the influence of both magnetic poles is equally exerted upon it. As we move northward, the marked end of the needle dips; as we move southward, the south-indicating end of the needle dips, but not until we arrive at the pole itself is the dip vertical. There, and only there, is the influence of each magnetic pole complete, to the total exclusion of disturbing influences.

Can there be any doubt that, subject to the deflection caused by the subordinate poles and by local causes,

exactly the same rule applies to the horizontal attractivness of the magnetic poles? As the poles are unsymmetrically placed in longitude, it will be at the pole, and only at the pole, that each will have full and complete effect. At the magnetic equator, the lie of the needle will, subject to the varying deflection already mentioned, be midway between the magnetic poles. The want of symmetry will then be halved, and the needle will point an equal distance away from both magnetic poles. As we move northward, the marked end of the needle will gradually approach the North Magnetic Pole; as we move southward, the other end of the needle will gradually approach the South Magnetic Pole; till, when we arrive at each pole respectively, the horizontally-balanced needle, having reached the main source of its attraction, will point indifferently in any direction. The sole effort of the needle is then to point downwards. Now let us take our stand in the immediate neighbourhood, *and due south*, of the North Magnetic Pole. It is evident that here the horizontally-balanced needle, in pointing to the magnetic pole, will—in so far as not obstructed by the great angle of dip—also point to the North Geographical pole. It will have no variation from the true north. We are at the source of an agonic line, or line of no declination.

We now move round to the other side of the North Magnetic Pole, and take our stand *between* it and the North Geographical Pole. The North Geographical Pole will now be due north of us, and the North Magnetic Pole due south. As the marked end of the

needle is attracted to the North Magnetic Pole, the south-indicating end of the needle will be pointing due north. We might say that there is here a variation of no less than 180 degrees, and it is not until we get farther away from the magnetic pole than the North Geographical Pole is, that the proper position of matters is restored, and the marked end of the needle points to the north. We should, then, if we continued in absolutely the same direction, travel along the opposite meridian from that on which we started—the meridian separated from the first by 180 degrees of longitude. We should, however, find by this time that the influence of primarily, the Asiatic focus, but also, to some extent, of the South Magnetic Pole, had diverted the needle, and that we were no longer on a line of no declination. The line of no declination would, in fact, be some distance in longitude removed from the meridian upon which we were journeying. Thus, when we take our stand in the immediate neighbourhood of the North Magnetic Pole, due north of it—although it is actually the south-indicating end of the needle which is pointing due north—we are standing at the commencement of another line of no declination.

It is evident that at the North Magnetic Pole these two positions are the only possible positions of no declination. The first is due south, and the second due north of the magnetic pole.

If we turn our attention to the South Magnetic Pole we shall find an exactly analagous state of matters. Just as at the North Magnetic Pole the positions due

south and due north of the pole are the only possible positions of no declination, so, at the South Magnetic Pole, the only possible positions of no declination are due north and due south of the pole; and in each case in one of these positions, though we are in reality at the begining of a line of no declination, we have a variation of 180 degrees —these positions being due north of the North Magnetic Pole, and due south of the South Magnetic Pole.

As regards the secondary poles, it is doubtful whether their influence is *absolutely exclusive* even in their immediate neighbourhood. If the dip is not vertical at these poles, the directive attraction in their proximity may also be incomplete. In considering the *origin* of the agonic lines we may therefore confine our attention to the primary poles.

The two primary poles thus account for the *origin* of four lines of no declination. Let us endeavour to trace out what becomes of these lines, and whether they are really distinct in their courses, or whether the two lines originated at either pole are in reality absorbed in those originated at the other pole.

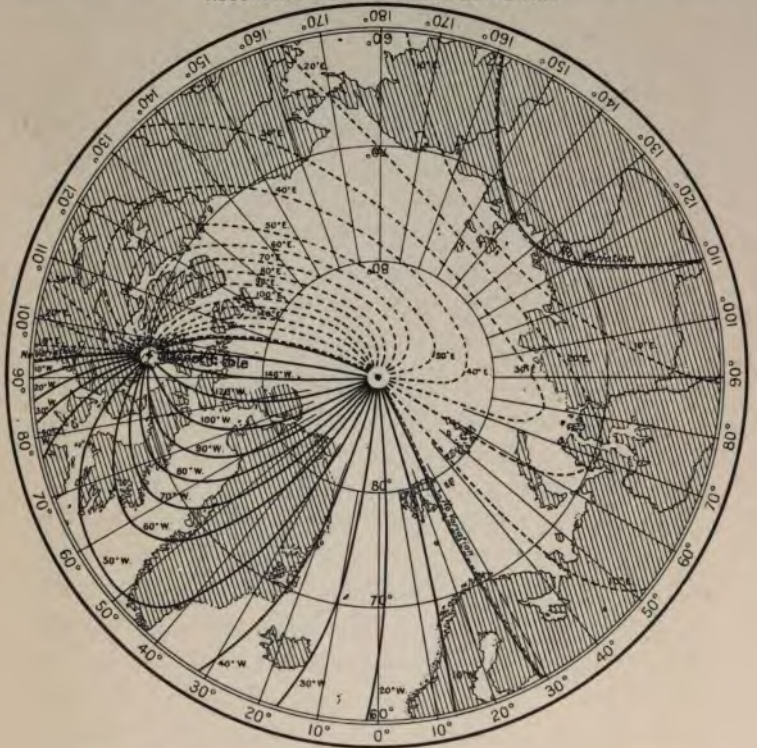
Let us start from the south side of the North Magnetic Pole. We are now in latitude 70° 5′ north, and longitude 96° 43′ west. Close to the magnetic pole, and due south of it, the direction of the magnetic needle coincides exactly with the geographical meridian 96° 43′ west. As we move due south, we at once find an easterly variation. The needle no longer points due north. It points to the east of north. As this can scarcely be occasioned by the influence of the Asiatic focus, from

which the distance is increasing as we proceed southward, we must seek some other explanation. An explanation may be found if we recall the position of the South Magnetic pole; which is 73½° south latitude, and—according to Ross's estimate—147° 30′ east longitude. The South Magnetic Pole is thus 115° 47′ of longitude west of the North Magnetic Pole, and 244° 13′ east of it, therefore its attraction on the south-indicating end of the needle is *westerly*. Thus, as we move due south from the North Magnetic Pole, following the meridian 96° 43′ W., the influence of the South Magnetic Pole gradually draws the south-indicating end of the needle towards the west, causing the marked end to be diverted towards the east, and thus producing an easterly variation.

Just as, in the neighbourhood of the Geographical Pole, to which the geographical meridians converge, the distance between the different meridians is necessarily very small, so, in the neighbourhood of the magnetic pole, to which the magnetic meridians converge, the distance between the different magnetic meridians must be very small. It follows that, near the magnetic pole, which is the chief source of the needle's attraction, by passing easterly or westerly only a moderate distance, we shall obtain a comparatively great angle of variation. As we move farther south and farther away from the North Magnetic Pole, the influence of the South Magnetic Pole will be stronger; but, for the reason mentioned, the resulting divergence of the needle will not be so manifest.

Let us now consider how the action of the South

NORTH POLAR LINES OF "NO VARIATION," AND EQUAL MAGNETIC DECLINATION ACCORDING TO THE ADMIRALTY CHART



Easterly Declination - - - - - - Westerly Declination———

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Magnetic Pole, in attracting the south-indicating end of the needle to the west, affects the line of no declination which we found in the immediate neighbourhood, and due south of, the North Magnetic Pole.

We have seen that, as we move southward, the marked end of the needle is caused to point to the east of the North Geographical Pole; and we find that in our southward journey we have thus to diverge more and more to the east to follow the line of "no variation."

We have seen that at the South Magnetic Pole, as at the North Magnetic Pole, there are only two possible positions of "no variation." One might naturally think, that the agonic line leaving the North Magnetic Pole on its southern side would unite with the South Magnetic Pole on its northern side, and that the agonic line leaving the South Magnetic Pole on its northern side would unite with the North Magnetic Pole on its southern side; that, in fact, the agonic lines proceeding southward from the North Magnetic Pole, and northward from the South Magnetic Pole, which in their origin we have dealt with as two separate and distinct lines, will be so influenced mutually by both poles that they will constitute in reality one line. The same reasoning would apply to the agonic line, leaving each magnetic pole on the opposite side, so that the agonic lines which in their origin we have dealt with as four separate lines, would naturally constitute only two lines.

It is, however, clear from the Admiralty Chart of magnetic variation, that the agonic line originating on

the southern side of the North Magnetic Pole shews no tendency, so far as its course has been traced, to unite with the agonic line originating on the *northern* side of the South Magnetic Pole. In fact, the authors of the Admiralty Chart have been driven to the conclusion that this agonic line must unite with the South Magnetic Pole, not on the northern side of the pole, but on the southern side. In the same way it appears that the agonic line which apparently originates on the northern side of the South Magnetic Pole, shews no tendency, so far as its course is traced, to unite with the agonic line originating on the southern side of the North Magnetic Pole; and the supposition of the authors of the Chart is that it must really unite with the North Magnetic Pole on its northern side.

We are endeavouring to follow the agonic line which originates on the south side of the North Magnetic Pole. The Admiralty Chart shews what we may assume to be this line, proceeding south-eastward through the whole of the American continent, and, at the farthest south point to which it appears to have been traced, the line is found in longitude 33 degrees west. This most southerly point of the line so far as apparently traced, is in latitude 60 degrees south. Throughout the part of its course extending from 30 degrees south latitude to 60 degrees south latitude (over every portion of which it appears to have been actually traced) this agonic line shews a *steady progress eastward.* The progress eastward during this portion of the course of the line is about 17 degrees, and up to the most southerly

point there is no indication of this eastward tendency discontinuing.

As the South Magnetic Pole is assumed to be in longitude 147° 30′ east, the longitudinal position of this agonic line at the extreme southerly point to which it seems to have been traced—about 33° W.—is practically diametrically opposite the meridian upon which the South Magnetic Pole is supposed to be. This position appears to render it highly improbable that the line can unite with the South Magnetic Pole on its northern side—more especially as the agonic line northwards from that pole is otherwise accounted for. It is therefore assumed that it must unite with it on its southern side, and to allow of this being the case, it is supposed that the eastward tendency of the agonic line—which has been very evident throughout its whole course so far—suddenly ceases when the latitude of 70° S. is reached. This agonic line is thus shewn as practically corresponding with a geographical meridian for the remainder of its course, and as passing over the South Geographical Pole on to the opposite meridian, and then uniting with the South Magnetic Pole on its southern side.

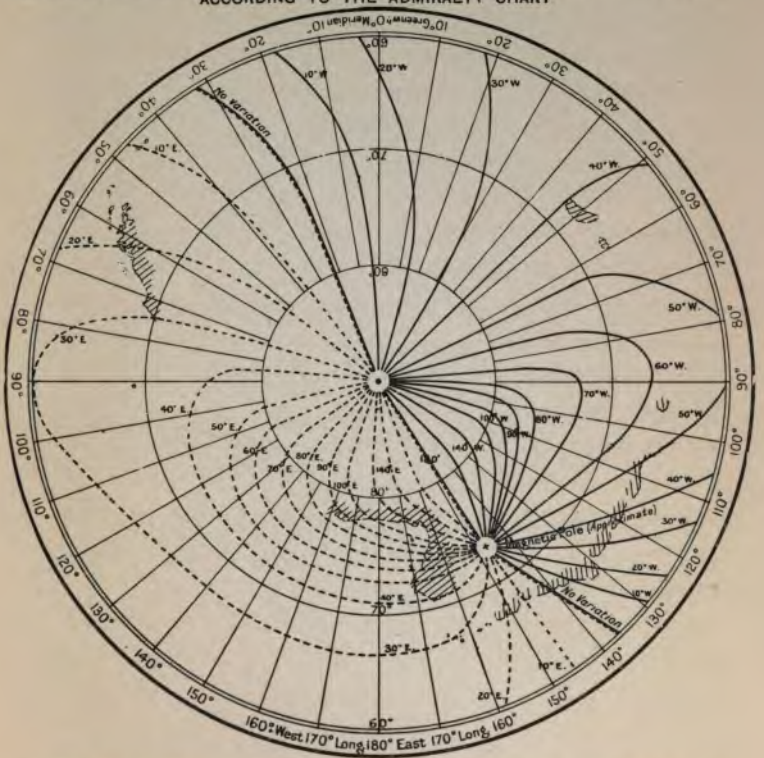
As the agonic line has not been traced in this region, there appears to be no reason whatever for this except the supposed exigencies of the case. The position of the line at the most southerly point to which it could be followed rendered it highly improbable that it could unite with the South Magnetic Pole on its northern side, and, as there are only two possible positions of

union, it seems to have been assumed that it *must* therefore unite with it on its southern side. The Admiralty Chart, it may be noted here, makes no reference to the existence of secondary poles.

It seems not improbable, in view of the longitude of this line—which we may call the American agonic line,—at its southern extremity, so far as definitely ascertained, that it is afterwards deflected by a secondary southern magnetic pole, or focus, corresponding with the secondary pole or focus which we have seen there is reason to suppose exists in the Northern Hemisphere. As has been mentioned, the position in longitude of the American agonic line at the most southern point to which it has been traced, is practically diametrically opposite that of the South Magnetic Pole, and the latitude to which this agonic line has been traced is not much more than 10 degrees north of the estimated latitude of the South Magnetic Pole, and therefore of the latitude at which a secondary pole or focus might also reasonably be looked for.

Now the European agonic line, which has been traced as far north as 80° N., passes far to one side of the (supposed) position of the Asiatic focus, and we should naturally expect that the American agonic line should be found in a corresponding position. The European line at 70° N. longitude, is about 80° west of the Asiatic focus, and 123° east of the North Magnetic Pole—a ratio of nearly 2 to 3. On a similar proportion, we should expect to find the South Magnetic focus somewhere about 90° east or west of say, 19° W., that being the

SOUTH POLAR LINES OF "NO VARIATION," AND EQUAL MAGNETIC DECLINATION ACCORDING TO THE ADMIRALTY CHART



(The South Magnetic Pole is now known to be about 8° further east than shown here.)

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supposed longitude of the American agonic line at 70° south latitude. Now, as shown in the next chapter, the position of the magnetic equator affords some evidence for supposing that the South Magnetic focus is situated at, or in the neighbourhood of 105° W. longitude, which would strengthen the suggestion made above that the American agonic line is deflected by this focus, if, indeed, it does not,—as appears to be not improbable,—actually unite with it.

It must, however, be admitted that our present information regarding the magnetic conditions of these desolate and almost unexplored regions is very limited, and thus we can only conjecture as to the actual state of matters. Although this is so, it would nevertheless, appear that the known facts harmonize with, and are to some extent explained by, the suggestions we have made.

Coming to the agonic lines from the South Magnetic Pole, the direct line will leave it on its northern side, on the meridian—taking the figures of the Encyclopædia Britannica—147° 30′ E.* and proceed north-westward. This line has to extend over only about 13½ degrees of latitude to reach the latitude to which the American agonic line has apparently been traced. In that distance it could scarcely pass from 147° 30′ E. to 33° W., so that *it* cannot be the termination of the American agonic line. It is, indeed, probably, the commencement of the other great line of no declination—the European agonic line. This agonic line passes southward from Spitzbergen

* See next note, p. 144.

through Europe, Arabia, and Western Australia, and has been actually traced to about 5 degrees north of the South Magnetic Pole. Its termination in the Northern Hemisphere will be treated of in the next chapter.

It thus appears to be probable that these two lines constitute the two great lines of "no variation" extending through both hemispheres. The Admiralty Chart appears to give support to such a view.

It remains for us to consider the lines originating on the north side of the North Magnetic Pole, and the south side of the South Magnetic Pole*—these being what may be called the "indirect" agonic lines.

* This line was crossed by a sledge-party from the *Discovery* in 1903, in longitude 156° E., and latitude 77° 40′ S. Guillemin's longitude for the magnetic pole, 154° 8′ E.—about 7° farther east than that given by the Ency. Brit., 147½°—is thus probably about correct.

CHAPTER XVIII.

The "indirect" agonic lines, and lines of equal magnetic variation.—The complexity of the influences affecting them, and the bearing of the shape of the Magnetic Equator on the positions of the secondary poles.

In this chapter we have to consider the course of the "indirect" agonic lines, which have their origin on the north and south sides of the North and South Magnetic Poles respectively, and which, commencing as lines having a variation of 180 degrees, only become lines of "no declination" when they get beyond the Geographical Pole. Before we do this, however, it will be advisable to examine the distribution of the lines of equal variation, so far as known.

If there are really four magnetic poles, as we have assumed, we should naturally expect that, in spite of the unsymmetrical positions of the poles, the lines of equal magnetic variation in the eastern and western magnetic hemispheres should be fairly symmetrical at corresponding portions of each hemisphere. Similarly we should expect that the lines in the northern magnetic hemisphere should on the whole be similar to those in the southern magnetic hemisphere.

But on examining a chart showing these lines of equal magnetic variation, we find that this is far from being the case. On the whole, except in the

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Magnetic Pole, in attracting the south-indicating end of the needle to the west, affects the line of no declination which we found in the immediate neighbourhood, and due south of, the North Magnetic Pole.

We have seen that, as we move southward, the marked end of the needle is caused to point to the east of the North Geographical Pole; and we find that in our southward journey we have thus to diverge more and more to the east to follow the line of "no variation."

We have seen that at the South Magnetic Pole, as at the North Magnetic Pole, there are only two possible positions of "no variation." One might naturally think, that the agonic line leaving the North Magnetic Pole on its southern side would unite with the South Magnetic Pole on its northern side, and that the agonic line leaving the South Magnetic Pole on its northern side would unite with the North Magnetic Pole on its southern side; that, in fact, the agonic lines proceeding southward from the North Magnetic Pole, and northward from the South Magnetic Pole, which in their origin we have dealt with as two separate and distinct lines, will be so influenced mutually by both poles that they will constitute in reality one line. The same reasoning would apply to the agonic line, leaving each magnetic pole on the opposite side, so that the agonic lines which in their origin we have dealt with as four separate lines, would naturally constitute only two lines.

It is, however, clear from the Admiralty Chart of magnetic variation, that the agonic line originating on

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at any rate, whatever makes the needle act as if the poles did rotate in the manner suggested—must make the causes conducing to the distribution of the lines a problem of the utmost complexity. Instead of having to deal with the relations of four fixed points, we have on this hypothesis, to deal with four continually moving areas, possibly of considerable extent; and as these are situated in very inaccessible regions on the earth's surface, the information regarding the lines in the neighbourhood of the magnetic poles, from which so much might be learned, is of the scantiest, if not, indeed, altogether wanting. Hence at present the difficulties in the way of following the influences affecting the indirect agonic lines with any certainty, are practically insuperable.

As regards the secondary magnetic poles, there appears to be strong reason to conclude that they must necessarily be of much weaker attraction than the primary poles, and therefore it is quite possible that, even in their immediate proximity, the direction of the needle may not be directly towards them. If this is so, the statement we have made regarding the primary poles, that an agonic line must certainly originate in the neighbourhood of each of them in a position due north and due south of the source of attraction, would not apply to the secondary poles. Probably, owing to the same cause, such agonic lines, if any, as are originated by the secondary poles, will extend only a short distance, as they will be overcome by the opposing influences.

We have seen that even as regards the direct agonic

lines, the influences deciding their courses are very complex. This complexity is necessarily much greater in relation to the "indirect" agonic lines, which at their commencement are lines with a variation of 180 degrees, and the first part of whose course is towards the neighbouring geographical pole. It has to be borne in mind that the geographical poles have only an artificial relation to the direction in which the magnetic needle points. In the case of the North Magnetic Pole, the geographical pole is at a distance of about 20 degrees of latitude, and in the case of the South Magnetic Pole, at a distance of about 16½ degrees of latitude, and we might just as well pick out any other point at a distance of about 1,300 miles or 1,100 miles from the respective magnetic poles, and consider what variation the needle showed from such a point. If the exact locality of each magnetic pole were accurately known, and we could tell what variation the needle showed not from the geographical pole, but from the magnetic pole itself, as we moved away from it, the matter might be simplified.

Let us take our stand in the immediate neighbourhood of the North Magnetic Pole on its northern side, on the meridian 96° 43′ west. The marked end of the needle points south to the North Magnetic Pole, and the south-indicating end of the needle points north to the North Geographical Pole. We move northwards along the geographical meridian, and the marked end of the needle is drawn somewhat to the left through the influence of the Asiatic focus—which repels its south-indicating end, which is pointing towards it; the south-indicating

end of the needle is also drawn slightly in the same direction, through the influence of the South Magnetic Pole. As we proceed northwards, the left is of course the westerly direction, and, as these influences would to some extent counteract each other, the agonic line would be drawn out of the meridian of its origin only to the extent by which the influence of the Asiatic focus would exceed that of the South Magnetic Pole. The north-seeking end of the needle would therefore doubtless be drawn westward. Thus the variation would be reduced to less than 180 degrees, and would become a westerly variation.

In considering the direct agonic lines, we concluded that the line leaving the North Magnetic Pole on its southern side tended in an eastward direction, and that the line leaving the South Magnetic Pole on its northern side tended in a westward direction, and we found that the probable cause of the former line tending eastward was that the south-indicating end of the needle was being drawn westward through the influence of the South Magnetic Pole.

If, then, the *marked* end of the needle is being drawn westward, the line of no declination will doubtless be deflected towards the *west*. We should thus, probably, in following the line of no declination from the north side of the North Magnetic Pole, be obliged to move to the west of our position before the needle would again show the variation of 180 degrees. If we follow along the meridian 96° 43′ west, till we reach the North Geographical Pole, this effect would doubtless be

increased. We may suppose we pass over the North Geographical Pole, and continue our course on the opposite meridian, which is 83° 17′ east. As we pass on to the opposite meridian, the very large westerly variation which we previously had, becomes a comparatively small easterly variation, not through the needle changing its position to any material extent, but simply because we have changed our course. We were hitherto proceeding northward, and having passed over the extreme northerly point of the earth, our course is now necessarily southward. The variation, although its geographical direction has thus been changed from westerly to easterly, is still, of course, towards our left. The agonic line in its course may therefore be expected now to lie considerably to the east of longitude 83° 17′ E.

The influence of the Asiatic focus will now be drawing the north-seeking end of the needle eastwards with great effect, while the South Magnetic Pole will be drawing the south-seeking end of the needle eastwards by a constantly increasing power, the farther south we proceed. The influence of these poles is therefore contrary to each other, and will vary according to position. Exactly the same course of reasoning might be applied to the agonic line originating on the southern side of the South Magnetic Pole as a line with a variation of 180 degrees.

It would also apply to the direct and indirect agonic lines from the secondary poles—assuming such lines to exist. And a little consideration will show that the indirect lines from the secondary poles would

necessarily, soon after leaving these poles, be diverted far to the east or west, as the case might be, long before the geographical pole was reached, owing to the repellent power, on the opposite pole of the needle, exercised by the far stronger primary magnetic pole. Hence it is quite possible that, after all, the direct agonic line from the primary South Magnetic Pole may curve round and join the Asiatic focus in high northern latitudes.

It is evident that the indirect agonic lines from the primary poles will be deflected to a great extent by the action of the subordinate foci towards which they respectively, at their origin, in a great measure tend; and to a minor, but gradually increasing extent by the action of the opposite magnetic pole. With these influences acting in opposite directions, the extent of the deflection will vary accordingly to position, the influence of the subordinate focus at first prevailing, and afterwards the influence of the opposite magnetic pole. This might naturally result in a curve being produced.

It will be seen from the numerous difficulties which are unavoidable in a consideration of these "indirect" agonic lines, in the present state of our knowledge of the subject, that it would be fruitless to endeavour to trace them, and to speculate as to how they are influenced at different localities.

We must remember, also, that the agonic lines are not fixed like meridians of longitude, but apparently sway to and fro owing to the secular motion of the magnetic poles. Thus the line of "no variation" passed through London in 1657, travelling eastwards, and is now, in

the same latitude, about 30° to the east, though it is now travelling west again,—using the word "travelling" in a very restricted sense. For, as explained in a later chapter, owing, no doubt, chiefly to local causes, there are frequently large deviations in places not far removed from one another, so that the lines on the charts are merely the *approximate average* of that locality.* With such wholesale changes in the agonic lines, the disposition of the lines of equal magnetic variation will also be correspondingly revolutionized.

Let us now consider the large oval on all parts of which there are no variation, and which we may suppose is really connected with these conjectured "indirect" agonic lines. This oval curve of "no variation" lies in Eastern Asia, its longer axis being in longitude 130° east, and its shorter axis in latitude 50° north. Let us imagine ourselves on any part of this curve, and see how the opposing attraction of the magnetic poles and relative foci would be likely to act, assuming the geographical position of the magnetic poles to be 70° 5′ N, 96° 43′ W; and 73° 30′ S, 147° 30′ E, respectively.

The curve intersects the parallel 20 degrees N., in longitude 140 degrees E. Let us suppose the magnetic needle, in this position, to be influenced by the North Magnetic Pole alone. The longitudinal separation from this pole, measuring eastwards from the position specified is 123° 17′. The needle would, therefore, no doubt, point in a north north-easterly direction, and thus the marked end of the needle, so far from coinciding

* See Appendix, No. V.

in direction with the geographical meridian, as it must do to show no variation, would show an appreciable easterly variation. Now consider the influence of, first, the Asiatic focus, and then of the South Magnetic Pole. The former must attract the *marked* end of the needle in a somewhat westerly direction, and the latter must attract the *south-seeking* end in a south south-easterly direction. Thus these two sources of attraction act in unison, and counteract the influence of the North Magnetic Pole in drawing the marked end of the needle towards the east. The result is that the needle, being equally attracted in opposite directions by opposing forces, points towards the true north.

By thus allowing for the different sources of attraction, a reasonable comprehension of the action of the needle on this curve of "no variation," may probably be arrived at. Seeing, however, that there are so many matters lacking in connection with this branch of our subject, these suggestions are put forward very tentatively, in the hope that they may help towards a clearer understanding.

While there is, in the Southern Hemisphere, no known district of "no declination" corresponding with this oval curve which occurs in the Northern Hemisphere, there certainly is, in the South Pacific, a district which has an apparent resemblance to it. Certain curves appear in which the declination is small, the smallest being 7 degrees east. The longer axis of this ellipse almost coincides with the geographical equator, and the shorter axis with the meridian 140 degrees west. In the

case of the ellipse in the Northern Hemisphere, the longer axis is longitudinal, and the shorter latitudinal, but in the ellipse in the Southern Hemisphere the reverse is the case. Of course local causes would readily account for an agonic line passing out of existence and becoming a line of small variation.

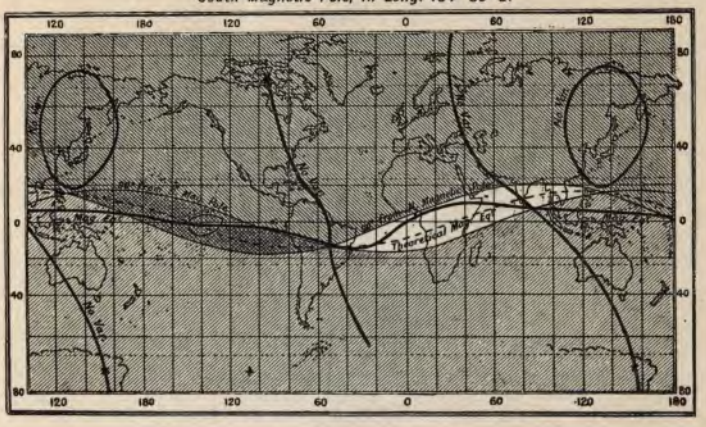
It is not improbable that both these ellipses are connected with the "indirect" agonic lines which must originate at the magnetic poles, as well as with the influence of the rotating polar extremities.

There is one point, however, in connection with the oval of easterly variation in the Pacific, of great significance, and that is that the magnetic equator passes through the centre of it. Further, this oval is almost exactly half way on the shortest line between the primary magnetic poles, being about 79° of a great circle from each of them. This is shown on the annexed chart of the world, on which lines are drawn showing the boundaries of 90° circles drawn from each of the primary poles. The theoretical magnetic equator thus formed is shown by the thin line drawn between them, and the actual magnetic equator, according to Evans, by a broad line. It will be noticed that in the Pacific there is an area where the circles, so to speak, overlap, and a corresponding area in the opposite hemisphere where they do not meet. This is due to the unsymmetrical positions of the poles, and must no doubt have some effect in the distribution of the lines of variation.

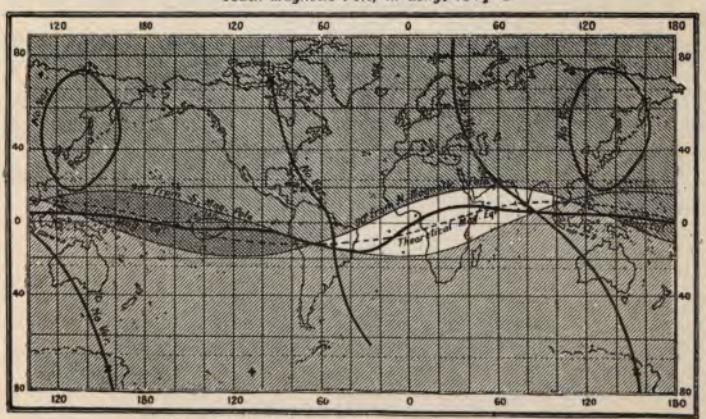
Comparing the theoretical with the actual magnetic equator, it will be seen that they by no means coincide,

DIAGRAMS SHOWING GEOGRAPHICAL POSITION OF CIRCLES 90° FROM THE NORTH AND SOUTH MAGNETIC POLES.

I.—North Magnetic Pole, in Long. 96° 43′ W.
South Magnetic Pole, in Long. 154° 30′ E.



II.—North Magnetic Pole, in Long. 125° W
South Magnetic Pole, in Long. 154½° E



Actual Magnetic Equator shown by broad line.
Theoretical Magnetic Equator shown by dotted line.

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but curve irregularly in relation to each other. It is curious to note that a far more symmetrical effect is obtained by assuming that the North Magnetic Pole is about 20° of longitude farther to the west. The result is shown in chart 2.

The magnetic equator, then, goes farther north and farther south than the theory of two magnetic poles would lead us to expect, but by assuming the existence of four magnetic poles we can explain some of its deviations. Directly south of the assumed longitude of the Asiatic focus, there is, as we might expect, a flattening of the curve, of no great extent, suggesting that this focus is in high northern latitude. When we look for a similar influence on the part of the supposed South Magnetic focus, we find a somewhat similar, but more decided diversion at about longitude 105° to 110° W., suggesting that its cause may be nearer the equator than the Asiatic focus is. The question naturally arises whether an irregularity in the magnetic equator, such as we have indicated, can really reveal the situation of the South Magnetic focus.

It is worthy of remark that the location of such a focus at about 105° W. would harmonize with the position required on the analogy of the European agonic line and the Asiatic focus—as has been suggested in the preceding chapter.* It is also to be noticed that the Southern focus, if in this position, would be 35° of longitude east of the centre of the South Pacific oval. This is not very dissimilar from the distance the

* See page 142.

Asiatic focus—in its supposed longitude—is west of the centre of the oval of "no variation" in the Northern Hemisphere, and which encloses an area of slight westerly variation. It may be further noted that, in the Northern Hemisphere, the lines showing equal magnetic variation are very much closer together on that side of the primary pole on which the longitudinal distance from the secondary pole is greatest. On the same analogy, we should expect the region of closest lines in the southern hemisphere to be similarly situated with reference to the two Southern Magnetic Poles, and a glance at the chart shows that this is indeed the case. We have, therefore, fair reason for believing that the position we have assigned for the Southern Magnetic Focus is approximately correct.

Now, the western extremity of the Pacific oval, coincides with a point almost exactly half way on the shortest line connecting the two secondary poles,—assuming they are situated in the longitudes mentioned above: we have also seen that its centre is half way between the primary poles,—also on the shortest line between them. It would thus appear that the oval in the Pacific is *nearly equidistant from all four poles*, which would lead to an abnormal state of magnetic conditions. The north and south primary poles would cause the needle to point N.E. and S.W., their influences strengthening one another; on the other hand, the two secondary poles would both pull it in the opposite direction, but with less force. Hence on the whole the variation would be slightly easterly.

We should expect that there would be a corresponding abnormal state of magnetic conditions at the diametrically opposite part of the earth, which is also equidistant from all four poles; the chart, however, gives no indication of such being the case. Nevertheless, it is curious to note from Weyer's Tables, that, in this very locality, at Sokotra, South Madagascar, and Mauritius, the needle never points to the true north, but always to the west of it, suggesting the possibility of an oval of *permanent* westerly variation. A similar oval might exist in eastern North America, where, as we have seen, the needle, over a large area, also points permanently to the west. And if these ovals of permanent westerly variation exist, it will be seen that the American one is situated, with respect to the American agonic line and Pacific oval, very much as the African one is with reference to the European agonic line, and the "no variation" oval in Eastern Asia.

The position we have assigned for the South Magnetic focus, in longitude 105° W., is also in accordance with what we have said regarding the preponderance of the poles towards one hemisphere. The four poles would appear to be situated between 96° W. and 105° E., measuring westwards, or within 160° of longitude. That is to say, they are all, longitudinally, in one hemisphere. The charts of "lines of equal horizontal force" show that the area of greatest horizontal force lies almost entirely in this hemisphere, in the vicinity of the equator, with a tendency to rise to a maximum about the longitudes of the four magnetic poles.

It is noticeable, however, in connection with our suggestion as to the position of the Southern focus, that no agonic line, such as might be expected to occur in the neighbourhood of its northern side has hitherto been observed in this locality. This region of the South Polar area, however, has hardly ever been visited, and has never been explored beyond the 70th parallel, and it is quite possible that such a line may exist farther south.

There remain the diversions of the magnetic equator between Africa and South America. To whatever cause they are due, it is evident that on the whole they are very similar in intensity for both poles. The most likely explanation regarding them, is that they may be the result of the rotating polar extremities. A careful and continuous study of the position of the magnetic equator would doubtless throw considerable light on the secular changes of the magnetic poles.

CHAPTER XIX.

Local causes of deviation of the magnetic needle.—How the orbital displacement of any district is influenced by the axial rotation, and the bearing of this on the impact of the solar-projected electric waves.

In considering the influences which decide the direction in which the magnetic needle may point at any particular part, we have repeatedly made reference to the subject of "local causes." By local causes we, of course, mean the deviation resulting from causes other than those affecting the earth as a whole. Local causes which divert the needle from the true magnetic meridian are very common, and this in itself must necessarily prevent terrestrial magnetism from ever becoming an exact science.

Not only, however, are local causes of deviation of frequent occurrence in nature, but in this matter art has come to the aid of nature, and local causes of deviation are artificially increased. Of late years, the development of electric railways and tramways has greatly increased the difficulties of magnetic observation. Dr. Charles Chree states that with the arrangements customary in electric traction, when the cars are running, the effects on delicate magnetic instruments are visible at a distance of several miles. Several magnetic observatories, such as those at Washington,

Toronto, Batavia, Vienna, Paris, and Rome, have been completely upset, and most of those situated near large cities are in imminent danger. A new site has for this reason lately had to be sought for the magnetic observatory of Kew, and it has been found advisable to erect an observatory at Eskdale Muir, in the south of Scotland, which will, when completed, probably supersede the observatory at Kew, in so far as magnetic phenomena are concerned.

Even at sea the difficulties of observation have been artificially increased, as iron ships have now practically superseded those built of wood. Every iron ship in the course of its construction becomes a magnet through the inductive action of the earth's magnetism. Throughout the life of the ship, the magnetism induced during construction to a certain extent remains, although it is more or less affected by the voyages made, the effect varying according to direction.

Although, therefore, both on land and sea, the difficulties connected with magnetic observations have of late years been artificially increased, the natural causes of deviation of the needle, from the position which it would take according to the magnetism of the earth as a whole, are sufficiently numerous.

Captain Ettrick W. Creak, C.B., of the Royal Navy, refers to this matter in a recent address to the geographical section of the British Association. He states that there is an increasing difficulty in finding districts of only a few miles in extent where the observed values of the magnetic elements at different stations do not

differ more widely than they should, if we considered only their relative position on the earth as a magnet. He mentions two striking examples of local disturbance:—"In the Ropakivi district, near Wiborg, a Russian surveying officer, in the year 1890, observed a disturbance of 180°, or in other words, the north point of his compass pointed due south. At Invercargill, in New Zealand, within a circle of 30 feet radius, a difference of 56° was found." And in our own country, mountaineers have learned that, on certain mountain ridges in Skye, and elsewhere, it is impossible to find their bearings by means of the compass, as there is no saying in what direction the marked end will be pointing.

Captain Creak considers the principal cause of local disturbances to be the occurrence of magnetic rocks in the vicinity. Such rocks may, from their peculiar position, occasionally be present and fail to disturb the needle; but, on the other hand, it has been found that "the magnet would be capable of detecting large masses of magnetic rock at a depth of several miles."

These causes of disturbance are not confined to land, although, in Captain Creak's opinion, the needle is not affected by causes of disturbance at sea if a depth of 100 fathoms or more intervenes. In shallower waters, however, the needle is disturbed at sea just as much as on land. Captain Creak calls such areas of magnetic disturbance at sea "magnetic shoals." One of the most remarkable of these magnetic shoals was found off Cossack, N.W. Australia, the area of disturbance being

3½ miles long by 2 miles broad, with not less than 8 fathoms of water over it. The disturbance was sufficient to deflect the compass to the extent of 56°, and to increase the dip by 29°; and this at a distance of over 2 miles from land.

A magnetic shoal was recently located by the surveying ship *Research* in East Loch Roag, at the island of Lewis; and it was found that,—although, according to the usual experience, such causes of disturbance in the Northern Hemisphere attract the north-seeking end of the needle, and in the Southern Hemisphere repel it,—the magnetic shoal at East Loch Roag repelled the north-seeking end of the needle.

Mountainous districts are specially open to suspicion of magnetic disturbance, and this also applies to islands. It is said that the island of Bornholm, in the Baltic Sea, acts as a huge magnet, and that the resulting deflection on the compass is perceptible at a distance of nine and a half miles.

It will be seen, therefore, that from this cause alone the regularity of the magnetic meridians and curves of magnetic dip must be completely upset. In judging of the effect of the earth's magnetism, we can only endeavour to ascertain what the lines of meridian and dip would be if not so disturbed. We can almost assume that in no large area of the surface of the earth will the position of these lines be found in reality exactly where they should be theoretically.

There is another matter which may be conveniently referred to here as a possible cause of difference of the

magnetism in different districts; although, as it originates in the mutual relations of the sun and the earth, it cannot be classified under the heading of local causes.

We have suggested that terrestrial magnetism has its origin in electric waves from the sun being impelled against the earth. If we consider the orbital and rotational motions of the earth in connection merely with these waves, it is evident that these motions must, in different latitudes, and at different hours of the day, vary to a great extent. We have seen that the speed of axial rotation varies according to latitude, being at the equator 25,000 miles daily, while at the geographical poles it is non-existent. Thus, places at the equator will pass under the electric waves at an excessive speed, while the speed will decrease as the latitude increases.

Now, consider the orbital progress. The earth is dashing forward in its orbit at the average speed of 18½ miles a second, which is the *uniform* orbital speed of the earth's centre. If we imagine ourselves at a place situated at the equator, it is evident that at about 6 a.m., *when facing the direction of orbital progress,* we are moving forward in the orbit at the speed mentioned. As, however, we turn towards the sun in the axial rotation, and continue the turning movement till the sun again sinks below the western horizon, the movement of axial rotation is *reducing* the speed of orbital progression. We, at our station on the equator, are, so to speak, moving by the axial rotation backwards from the direction in which the earth as a whole is dashing

forward. The orbital movement of displacement, therefore, falls to be locally reduced.

The converse must be the case when the place at which we have taken our stand is turned away from the sun. We are then once again turning *towards the direction* of orbital progress, and we are thus moving forward in the orbit at a greater speed than the earth as a whole is moving forward. It would seem as if at 6 a.m., as we face the direction of orbital progress, the

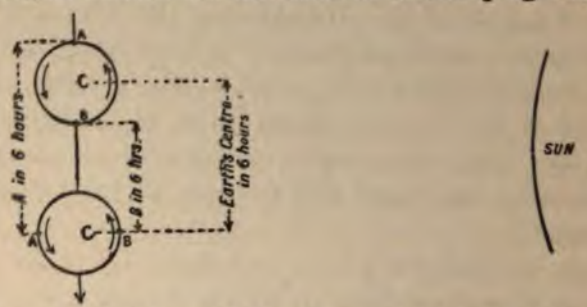


Diagram showing the amount of forward movement, in a period of 6 hours, of various points on the earth, resulting from the combination of the axial and orbital movements.

sole local displacement in the orbit is that produced by the orbital movement of the earth as a whole. At 12 noon, when we face the sun, the speed of orbital progression falls to be *reduced* by the speed of axial rotation; so that, at that hour, the change of position occasioned by the double movement of the earth, is *less* at the equator than at any other place on the earth's surface.

Taking the orbital velocity of the earth as a whole at 18½ miles a second or 1,110 miles a minute, and the

axial velocity at the equator at 17⅓ miles a minute, it would appear that, at about 12 o'clock noon, the orbital displacement occasioned at the equator by the double movement is 1,092⅔ miles a minute. At about 6 p.m., when we face the portion of the orbit through which the earth has just passed, the sole local displacement in relation to the orbit is again that of the orbital movement. For the next twelve hours, however, the displacement is *greater* than is accounted for merely by the speed of orbital progression, as the place at which we have taken our stand is turning axially in the direction in which the earth is progressing in its orbit. Thus the orbital displacement falls to be increased to a varying extent up to the maximum at 12 midnight, when the whole axial velocity falls to be added to the orbital velocity, and the orbital displacement is therefore 1,127⅓ miles a minute, being greater than at any other place on the surface of the earth. But the portion of the earth, which is thus moving forward at a greater speed than the average orbital velocity, is not directly exposed to the sun, except in the neighbourhood of one or other of the poles—where the axial velocity is small.

It will be seen that this question of displacement would have a different bearing in different latitudes, although the average movement corresponds. Thus, at the equator the displacement at noon is less than it is at any other place on the earth, but at midnight it is proportionately greater. The increase in the displacement at midnight corresponds with the decrease at noon. This would apply to all latitudes.

How, then, does this bear on the impact of the electric waves from the sun? It is only at the equinoxes that the sun is directly over the equator, so that it is only then that the full effect of the reduction in the speed of orbital displacement, occasioned by the axial rotation, would occur at the centre of the sheet of electric waves. At the equinoxes, also, the sheet would stretch from one geographical pole to the other, or, strictly speaking, a little beyond each pole, as mentioned on p. 37.

On the other hand at the solstices the centre of this sheet will lie either considerably ($23\frac{1}{2}^{\circ}$) to the north or considerably to the south of the equator, whilst one geographical pole and its adjacent magnetic poles will be excluded, and the other corresponding poles continuously exposed to the influence throughout the diurnal rotation. This variation in the exposure of the respective magnetic poles to the direct influence of the sun, must, doubtless, if the sun is the source of the earth's magnetism, have an appreciable effect on the movements of the magnetic needle, and this effect will, of course, vary, according to the geographical position of the needle. In its broad aspect this subject has already been referred to, and we have seen that the extent of the needle's movements is noticeably greater in summer than in winter.

One cannot but suppose also that the differences arising in different localities in connection with the speed at which the zone of electrical influence is traversed, and the varying amount of orbital displacement—as well as the speed of what we might call the

reverse movement, when the position is turned away from the sun, in relation also to the orbital velocity—must have some bearing not only on the working of terrestrial magnetism in the earth as a whole, but also on the diversity of the needle's movement in different localities. There is reason to believe that the rotational movement of the sun itself must exercise an important influence on the earth's magnetism — an influence complicated by the period of rotation varying according to the solar latitude. At the solar equator, the period is about 25 days, whilst at 45° it is over 27 days; and it is supposed to be somewhat less in the northern, than in the corresponding southern latitudes. Furthermore, the fact that the solar axis is not a perpendicular to the plane of the ecliptic—the solar equator being inclined to the ecliptic at an angle of 7° 15′—must not be overlooked in estimating the various causes which go to produce the periodical changes in the magnetic state of the earth. It is, however, at present impossible to analyse how these various causes influence the movement of the magnetic needle in different situations; and it can only be by slow and patient investigation that the effect of these diverse causes on the action of the needle can be definitely ascertained.

CHAPTER XX.

Some factors that may be found to have some bearing on the movements of the magnetic needle.

We have endeavoured to account for the existence of terrestrial magnetism by the impact on the earth of electrical displacements in the surrounding ether, having their origin in the activity of the sun. We have seen that, if this explanation is correct, the two points which we have described as the orbital poles—being the apices of the earth at right angles to the plane of the orbit—might naturally be expected to be the positions of the magnetic poles, and we have considered certain reasons which go to explain why such cannot be continuously the case.

It has also been conjectured that, if the earth took the same time to rotate on its axis as it does to revolve around the sun, the magnetic poles might follow the movement of rotation, and consequently practically coincide with the orbital poles, and thus describe a circle around the corresponding geographical poles in the period of rotation. If this be really the case there would seem to be a strong probability that the extent of the daily movement of the magnetic pole, or of the centre of primary attraction in the magnetic pole, should bear

somewhat the same proportion to the length of the circumference of the circle of latitude on which the magnetic pole is situated, as the *time* occupied by the earth in the daily rotation bears to the *time* occupied in the annual revolution.

Unfortunately, the hypothesis that there are four magnetic poles has the effect of producing a complexity which precludes definite information on this subject, for, in the present state of our knowledge, we cannot tell to what extent each pole contributes to the daily motion of the needle. Moreover, the existence of four poles instead of two raises questions as to whether we are to double or halve the ratio above mentioned. Nevertheless, assuming that the whole resultant motion of the needle at Kew is caused by the primary North Magnetic Pole alone, it will be of interest to enquire what the extent of the daily movement really is, and what proportion it bears to the circle of latitude on which the North Magnetic Pole lies.

By the time of daily rotation we, of course, in this matter, refer to the interval which elapses between the successive returns of each meridian to the same position in relation to the sun. The actual time of one complete rotation—the sidereal day—is about four minutes less than the solar day, but it is the latter with which we are now concerned. The length of the solar day is on the average exactly 24 hours, and the time occupied by the earth in the annual revolution is practically 365¼ days. Let us enquire whether there is any reason to think that these proportions do really apply.

It will be seen from the table of the daily variation of the magnetic needle at Kew, which is given in Chapter VI, that the total average daily movement of the needle is 28·37 minutes easterly and 28·34 westerly, making together a movement of 56·71 minutes. By taking the half of this total movement we shall get the measurement of the diameter of the daily circuit as traced by the movement of the magnetic needle at Kew, assuming that the whole movement is caused by the North Magnetic Pole. The diameter is thus 28·355 minutes of arc.

If we now accept the position specified by Ross for the North Magnetic Pole, we may assume that the daily movement of the needle at Kew occurs with the pole in latitude 70° 5′ north and longitude 96° 43′ west. Let us, on this assumption, measure the actual geographical length of the diameter of the daily circuit of the magnetic pole, or of its centre of primary attraction. The diameter is subtended by an angle of 28·355 minutes at Kew. To enable us to measure its actual length, we must first get the distance of the magnetic pole from Kew.

Let us construct a triangle * one side of which will be a line from Kew to the North Geographical Pole, its length being 38½ degrees of geographical latitude. The second side will be a line from the North Geographical Pole to the North Magnetic Pole, its length being 19° 55′ of latitude, and the angle contained between these two sides will be 96° 43′. We find that the length of the third side, being the distance of the magnetic pole from

* See Appendix; No. II.

Kew, is equivalent to 44° 40′ of latitude, and that the angle at Kew is 28° 46′.

We can now construct another triangle of which one of the sides is the distance from Kew to the North Magnetic Pole, which we have just found to be equal to 44° 40′ of latitude. The second side is also a line from Kew to the North Magnetic Pole, and is of practically the same length, but forming an angle at Kew of 28·355 minutes (say 28 minutes) with the first side. The third side of the triangle will then be the length of the diameter of the small daily circuit. By this means we find that the diameter of the daily circuit is nearly 20 minutes (say 19′ 40″) of the circle.

It is evident that this measurement relates to the same great circle as the other two sides of the triangle—the sides extending from Kew to the North Magnetic Pole. The distance from Kew to the North Magnetic Pole is 44° 40′ of the circumference of a circle surrounding the earth passing through both geographical poles. We have therefore now found that the diameter of the daily circuit at the North Magnetic Pole is 19′ 40″ of the same great circle.

If we take the circumpolar circumference of the earth as 24,815 miles, the diameter of the daily circuit at the magnetic pole (being 19′ 40″ of the circumpolar circle) will be about 22·6 miles. The actual length of a degree of longitude at parallel 70° 5′ is 23·5 miles, making the total length of the parallel 8,460 miles. It would thus appear that the daily movement in longitude of the North Magnetic Pole, or of its centre of primary

attraction—22·6 miles—is slightly less than the length of a degree of longitude (23·5 miles) at parallel 70° 5′, and would therefore, if increased by the curvature of one degree of the parallel, bear about the same proportion to the length of that parallel as the time occupied in the axial rotation, 24 hours, bears to the time occupied in the annual revolution, 365¼ days.

Now we have assumed that this motion is produced by the daily rotation of the earth, and that the movement, being of a circular nature, is therefore practically a reverse movement during one half of the day from what it was in the preceding 12 hours. We might describe the semi-circle, travelled over in one period of 12 hours, as a forward movement, and the semi-circle travelled over in the ensuing twelve hours as a backward movement, so that the pole is virtually thrown back into its previous position.

Now, if the daily rotation of the earth instead of occupying 24 hours occupied 365¼ days, this forward movement, which coincides with one half of the daily rotation would extend not merely through 12 hours, but through 182⅝ days; and if in 12 hours the movement covers, as estimated, about one degree on the parallel, in 24 hours it would cover about 2 degrees. Thus in 182⅝ days it would cover about 360 degrees, or the whole circumference of the circle. This brings out the rather surprising result—assuming the whole motion of the needle to be due to the North Magnetic Pole—that if the diurnal rotation occupied the same time as the annual revolution now occupies—365¼ days—instead of

only 24 hours, the magnetic pole would in the period of rotation travel twice round the circle of latitude.

The above calculation does not, however, appear to have any special bearing upon the secular movement of the magnetic poles under existing circumstances. It seems not unlikely that the period of the secular movement of the magnetic poles may really bear some relation to the period of the annual revolution of the earth in its orbit, but the evidence at present available does not allow of an opinion being expressed as to whether there is any direct relation between these periods or not.

In the calculations we have made in certain of the preceding chapters, as to the daily motion of the North Magnetic Pole, as revealed by the daily movements of the magnetic needle at different stations in the Northern Hemisphere, we have found that the evidence appears to indicate a daily circular movement at the pole. Now, we have seen that the *secular* movements of the needle at various places go to show that the magnetic pole is really elliptical in shape, and that the secular movement of the pole is practically a rotation on its own axis, as if it revolved on a "pivot"—its geographical situation not altering to any great extent. We have inferred that, as regards the magnetic pole as a whole, the daily movement consistent with its shape would be a swing of small extent; and yet we have concluded that as regards the extremities of the ellipse—or, as we may call them in relation to these stations, "the centres of primary attraction"—the daily movement is rotatory. These two movements—a swinging movement of the pole as a

whole, and a rotatory movement of the extremities—are consistent with each other only if we allow for a certain amount of "play" at the central "pivot," whereby the pole as a whole will have a certain daily range of movement in both latitude and longitude. The extremities will thus be caused by the daily swing of the pole to move around the circumference of a small circuit. This subject is dealt with in Appendix No. VI.

One other matter may be brought up here, which may have some relation to the daily movement of the needle. In Chapter VI. we mentioned that the magnetic poles had a daily swinging movement with reference to the sun—which might also have some bearing on the needle's daily movement. Now, the earth's axis has also a similar movement to and from the sun, not daily, but six-monthly, from solstice to solstice. The earth's axis being inclined 23½° to the plane of the ecliptic, the geographical poles thus swing 23½° on each side of the ecliptic, or 47° in the six months between the winter and summer solstices. The result is that the surface of the earth meets the electric waves from the sun in an ever-changing manner, as the axis of rotation slowly sways to and fro. This might be expected to alter the magnetic conditions, and to have an effect varying in different parts of the earth. This has doubtless a bearing on the gradual seasonal changes in the movements of the magnetic needle.

CHAPTER XXI.

Sun Spots, Polar Auroræ, and Magnetic Storms, considered in connection with the hypothesis of the magnetization of the earth by the impact of solar-projected electric displacements in the ether.

THAT there is a certain connection between the phenomenon of terrestrial magnetism and the occurrence of sun spots and auroræ is now generally accepted, but the nature of the connection, and the relation between these phenomena have not yet been definitely ascertained.

M. Guillemin gives the table on the next page, which he states was prepared by Professor Loomis, of Yale College, U.S.A., showing the coincidence of the epochs of maxima and minima of these various phenomena, and he mentions that the observations of the two eminent astronomers Respighi and Tacchini, confirmed the fact that outbursts of the "red prominences," or spouts of hydrogen gas, on the sun, follow the same law as the spots.

M. Guillemin refers to the fact that in 1859 a magnetic storm of unprecedented magnitude continued from August 28th to September 7th, and that this was found to be absolutely simultaneous with the period of maximum activity of one of the largest sun-spots ever observed.

The larger sun spots are now believed to be the result

of, or at least to indicate, very violent commotions on the surface of the sun. The spots themselves are considered to be depressions in the solar surface, the apparent blackness being simply the result of contrast with the intense light of the surrounding parts. The spots are of course in reality of immense size, and they are constantly undergoing great changes through the

Periods of Maxima of—*			Periods of Minima of—*		
Sun Spots.	*Magnetic Needle. Amplitude of Diurnal Variation.*	*Aurora Borealis.*	*Sun Spots.*	*Magnetic Needle. Amplitude of Diurnal Variation.*	*Aurora Borealis.*
1778	1777	1778	1784	1784	1784
1788·5	1787	1787·5	1798	1799·5	1798
1804	1803	1804·5	1810	.....	1811
1816·5	1817·5	1818	1823	1823·5	1823
1829·5	1829	1830	1833·5	.....	1834·5
1837	1838	1840	1843·5	1844	1843·5
1846·5	1848·5	1850·5	1856·5	1856	1856
1860	1858·5	1859·5	1867	1867	1867
1870	1870·5	1870·5	.....	.....	.....

action of the violent disturbances of which they are the indication. One spot, noticed in 1851, was 140,000 miles across, and the commotions were so great, that they could be detected by observation with the telescope. In fact, it would appear that sun spots are indicative of perturbations in many respects analagous to volcanic eruptions.

It was discovered in 1843, that the number of spots appearing on the sun's surface is subject to a periodic

* Electricity and Magnetism, page 79.

fluctuation, which gradually falls from a maximum to a minimum, and then gradually increases to a maximum again, the period of transition being a little more than eleven years. Later on, Dr. Rudolf Wolf, of Berne and Zurich, discovered that the sun-spot period exactly coincided with the periodicity of magnetic disturbances on the earth's surface, thus proving, or at least giving strong reason to suppose, that magnetic storms and sun-spots are really in some way connected.

Physicists have, in the same manner, been gradually forced to conclude that magnetic storms and the aurora are connected. As M. Guillemin says, "It is now generally allowed that this phenomenon (the aurora) is closely bound up with the earth's magnetism, and that magnetic storms and auroras arise from a common cause rather than that they are cause and effect." *

Thus, by slow and patient investigation, the conclusion has been arrived at, and is now, as we have mentioned, generally accepted, that a connection of an undefined nature exists between these three natural phenomena—sun spots, magnetic storms, and auroræ.

M. Guillemin gives much interesting information as to the investigations which have been made regarding the aurora. While occasionally seen in tropical and temperate regions, the aurora is, of course, of much more frequent occurrence in the polar areas, and, as it has naturally been most closely observed in the northern regions, it has amongst ourselves become known as the northern lights or aurora borealis. According to recent

* *Electricity and Magnetism*, p. 79.

authorities, the displays of aurora australis are usually simultaneous with those of the aurora borealis.

M. Martins, one of the scientists who has given special attention to the investigations of the nature of aurora, writes regarding it in the following graphic terms:—"The phenomena (of the aurora in the Arctic regions) are seen with a splendour and magnificence not comparable with anything else. Brilliant and varied as a display of fire-works, the sight changes every moment. There is not time for the painter to catch the form or tint of their changing lights. Even the poet fails to describe them. Never are there two auroras alike,—their variety is infinite." *

It is believed by some of the inhabitants of the Arctic regions that the aurora is accompanied by a peculiar rustling noise, although many scientists are of the opinion that this is an illusion. It is interesting, however, to know that in Finland, such a belief is common. The Laplanders compare the noise to what is produced by the leg-joints of the reindeer during their walk, which resembles the crackling noise of electric sparks.

The late Baron N. A. E. Nordenskjold, who led an expedition which passed the winter 1878-79 in Bering Strait, has stated that during the whole of that winter, although there were no brilliant displays, the aurora was observed as a luminous halo-light arc, and he concluded that, "our globe even during a minimum aurora year, is adorned with an almost constant crown of light, single, double or multiple, whose inner edge was usually,

* *Electricity and Magnetism*, p. 92.

during the winter 1878-79, at a height of about ·03 of the radius of the earth (120 miles) above its surface, having its centre a little north of the magnetic pole, and having a diameter of about ·32 of the radius of the earth (about 1,280 miles)."

Dr. Sophus Tromholt, another explorer, who spent the winter 1882-3 in Lapland for the express purpose of studing auroræ, came to the conclusion that "the auroral zone does not lie quite still, but shifts northward and southward daily, and that it has a yearly motion, and also a motion which recurs in an eleven-year period."

The height of the aurora has been variously estimated, by different investigators on different occasions, at from 81 to 241 miles. One or two observers, however, have stated that occasionally the aurora occurs at practically the surface level.

Dr. Silvanus P. Thompson mentions, in connection with the relation between the aurora and terrestrial magnetism, that it was first noted by Wilcke, a Swede, that the corona of the aurora *forms in the magnetic zenith*, and that it was first pointed out by Ussher in 1788 that the *magnetic meridian* bisects the auroral arch.

Although magnetic storms are of so irregular a character as to render their accurate prediction impossible, it has nevertheless been found that they recur in certain fixed periods. It is said that they are more frequent during the night than during the day, and that in the Northern Hemisphere they are more frequent and noticeable during the months from April to

September than during the winter months. In the Southern Hemisphere, their greatest frequency is from September to April, which is the summer season of that Hemisphere, so that their more frequent occurrence during the summer months applies to both hemispheres alike. It has been found, however, that sometimes isolated magnetic storms occur all over the world at the same moment, even at places several thousands of miles apart. A magnetic storm of this nature occurred on 25th September, 1841, and was observed simultaneously in Canada, Bohemia, the Cape of Good Hope, Tasmania, and Macao.

The observed simultaneous occurrence of a sudden solar change and of a marked magnetic disturbance, which took place on 1st September, 1859, is particularly referred to by Dr. Balfour Stewart in his article on terrestrial magnetism in the Encyclopædia Brittanica. At noon on that date, the late Mr. R. C. Carrington, the well-known astronomer, was observing through his telescope a large sun-spot. He describes what occurred, and his impressions as follows:—

"Within the area of the great north group (the size of which had previously excited general remark) two patches of intensely bright and white light broke out. I noted down the time by the chronometer, and, seeing the outburst to be very rapidly on the increase, and being somewhat flurried by the surprise, I hastily ran to call someone to witness the exhibition with me, and, on returning within sixty seconds, was mortified to find that it was already much changed and enfeebled. Very shortly afterwards, the last trace was gone, and although I maintained a strict watch for nearly an hour, no recurrence

took place. . . . The instant of the first outburst was not fifteen seconds different from 11h. 18m. Greenwich mean time, and 11h. 23m. was taken for the time of disappearance. In this lapse of five minutes the two patches of light traversed a space of about 35,000 miles. It was impossible, on first witnessing an appearance so similar to a sudden conflagration, not to expect a considerable result in the way of alteration of the details of the group in which it occurred, and I was certainly surprised, on referring to the sketch which I had carefully and satisfactorily finished before the occurrence, at finding myself unable to recognise any change whatever as having taken place. The impression left upon me is that the phenomenon took place at an elevation considerably above the general surface of the sun, and accordingly altogether above and over the great group in which it was seen projected. It has been very gratifying to me to learn that Mr. Hodgson chanced to be observing the sun at his house at Holloway on the same day, and to hear that he was a witness of what he also considered a very remarkable phenomenon."*

Dr. Balfour Stewart, in writing with reference to Mr. Carrington's statement, says "at the very moment when Carrington observed this phenomenon, the three magnetic elements at Kew were simultaneously disturbed. The disturbance occurred as nearly as possible at 11h. 15m. a.m., affecting all the elements simultaneously, and commencing quite abruptly. The first or most abrupt portion of the disturbance lasted only about three minutes for all the elements, but after that there was a more gradual change in the same direction before the curve turned. This more gradual continuation of the first sudden movement lasted about

* *Philosophical Transactions*, 21st Nov., 1861.

seven minutes for all the elements. This magnetic disturbance was, however, in reality a small one, and was followed by a very great disturbance, which took place not many hours afterwards."

This all goes to show that the belief in a relation between the occurrence of prominent sun spots (and other solar changes), conspicuous auroræ, and magnetic storms, is well founded.

This being so, we have to consider whether the theory propounded in the preceding pages in regard to terrestrial magnetism is consistent with such a relation, and, if so, whether it can be made to furnish any information as to the nature of the connection.

We have surmised that the earth is an electro-magnet with unsymmetrical poles, magnetized by the impact of electrical displacements in the surrounding ether projected outwards from the sun. Now, if the sun originates these electrical waves, is it not probable that these will be affected by the occurrence of tremendous commotions in the sun, such as are indicated by what we call sun spots? Must not these disturbances, in the line of their activity, influence the electrical currents which are being impelled towards the earth, actually, to a certain extent, from themselves? We know that on the earth itself violent volcanic eruptions sometimes agitate the whole surrounding atmosphere for weeks or even months. As has been mentioned in a former chapter, Professor Silvanus P. Thompson and other scientists have supposed that the surrounding ether in which light is propagated, is not only the medium

through which also all electric and magnetic forces are propagated, but is nothing else than electricity itself. If this supposition is even partially correct, there is reason to believe that the occurrence of violent

Vibrations of the magnetic needle during a magnetic storm.

agitations in the great propagator of these electric and magnetic forces—that is to say, the sun—must have a certain effect on the forces propagated. If the sun is the fountain-head of the electric waves which magnetize the earth, violent disturbances in the sun will doubtless, to some extent, in the line of the activity of the disturbances, affect the character of these waves, and we have seen that sun spots are certainly an indication of the existence of such disturbances.

It is but a step further to magnetic storms. If the magnetization of the earth is, as we have conjectured, occasioned by the impact of electric waves or electric

displacements in the surrounding ether, then any change in the character of these waves or displacements may be expected to produce analagous changes in the resulting magnetism. If these electric waves are thrown into violent agitation by the influence of sun spots, will not their agitation be made evident in the magnetism which they produce? The magnetic needle is the revealer of the fluctuations in the magnetism of the earth, and it is thus to be expected that the changes in the magnetism will be made evident by the movements of the needle. May we not in this way explain how the occurrence of conspicuous sun spots is accompanied by the occasional violent perturbation of the magnetic needle?

It appears that in most cases the occurrence of sun spots is not actually *coincident* with the occurrence of the magnetic storms, but that magnetic storms, on the mean, commence 26 hours, and attain their greatest height 45·5 hours, after the transit of the spot across the central meridian of the sun.* It would appear that the effect of solar disturbance, of which the sun spot is an indication, is felt only in the line of activity of the disturbance. The line of activity may not be towards the earth at all. The spot may be visible to us, and yet the effects may pass by the earth; and it will only be when the earth comes into the line of activity, and encounters the agitated electric currents, that the effect of the disturbance will become evident by the perturbation of the magnetic needle.

As regards the phenomenon witnessed by Mr. R. C.

* *Knowledge and Scientific News*, p. 186, 1904.

Carrington, such a "conflagration" as he describes, occurring in the ether at some distance from the sun, would, no doubt, similarly (although on a small scale) affect the electric waves, and, in that case, it happened that these agitated waves were impelled towards the portion of the earth from which the phenomenon was observed, and thus the magnetism at that part was affected, and the magnetic needle suddenly disturbed.

In regard to the connection with the aurora, it is known that electricity and magnetism act and re-act on each other. We have supposed the earth to be magnetized by electric displacements in the surrounding medium. The resulting magnetism will in turn have a certain effect on the impact of these electric waves, and will probably, to a certain extent, deflect them towards the magnetic poles. These poles are, according to Dr. Silvanus P. Thomson, situated geographically almost at the localities of greatest cold, and he suggests that in such parts "there will be, at a certain height in the atmosphere above the earth's surface, a region where, if the air is descending, charged electrically, it will discharge itself downwards towards the earth with a luminosity like that in a Geissler's vacuum tube." *

We can readily imagine that if, in some such manner as this, these electric waves are actually the source of the aurora, they will, when agitated by solar disturbances, impart increased brilliancy to the resulting aurora.

The question of the association between sun spots, auroræ, and magnetic variations has been treated by

* *Electricity and Magnetism*, p. 127.

the late Professor E. Loomis, in the *American Journal of Science and Arts.* He writes—

"On the whole there seems to be no room for question that the number of auroras seen in the middle latitudes of Europe and America exhibits a true periodicity, following very closely the magnetic periods, but not exactly copying them. In particular, we notice that during those periods in which the range of the magnetic declination was unusually small, auroral exhibitions were extremely few in number and insignificant in respect of brilliancy. If now we inquire as to the probable connection between these three classes of phenomena, we cannot suppose that a small black spot on the sun exerts any direct influence on the earth's magnetism or electricity, but we must rather conclude that the black spot is a result of a disturbance of the sun's surface, which is accompanied by an emanation of some influence from the sun, which is almost instantly felt upon the earth, in an unusual disturbance of the earth's magnetism, and a flow of electricity, developing the auroral light in the upper regions of the earth's atmosphere. The appearances favour the idea that this emanation consists of a direct flow of electricity from the sun. If we maintain that light and heat are the result of vibrations of a rare ether which fills all space, the analogy between these agents and electricity would lead us to conclude that this agent also is the result of vibrations in the same medium, or at least that it is a force capable of being propagated through the ether with a velocity similar to that of light. While this influence is travelling through the void celestial spaces, it develops no light, but as soon as it encounters the earth's atmosphere, which appears to extend to a height of about 500 miles,* it develops light, and its movements are controlled by the earth's magnetic force, in a manner analogous to the influence of an artificial magnet upon a current of electricity circulating round it."

The late Professor Loomis, who was a distinguished mathematician, is a high authority on all meteorological phenomena; and the paragraph quoted seems to be corroborative of the hypothesis we have submitted as to the relations existing between sun-spots, the auroræ, and magnetic storms. It would therefore appear that the theory set forth as explanatory of the occurrence of terrestrial magnetism is not only quite consistent with the relations existing between these three natural phenomena, but is, at least to some extent, suggestive of the nature of the connection between them.

* Dr. Alexander Buchan gives the height of the atmosphere as from 120 to 200 miles.

CHAPTER XXII.

CONCLUSION.

LET us now briefly recapitulate certain of the deductions drawn in the preceding chapters, and the reasons on which they are based.

We have shown that there is scientific authority for the opinion that the space through which the earth moves in its orbital and diurnal revolutions is permeated by a medium of an electrical nature, and that there is reason to believe that, through the action of the sun, waves or displacements of this electrical medium will be impacted against the earth and its enveloping atmosphere, on the side turned towards the sun. As the earth in its diurnal movement rotates eastward, each portion of the earth in its turn passes under these electric waves, and thus a sheet of electric influence is daily caused to surround the earth, winding from east to west. In this manner the earth is magnetized by electric induction.

As the centre of this electric sheet will practically be on the orbital plane, the poles of the resulting electro-magnet—including what we have called the Asiatic and Southern foci—will be in the neighbourhood of the

apices of the earth in relation to the orbit, that is to say, in the neighbourhood of the Arctic and Antarctic circles. The exact geographical position of these poles will, however, be influenced by the internal structure of the earth as a magnet, as well as by the irregularities of its surface. From these causes, it results that the magnetic poles of the earth are, both in latitude and longitude, placed unsymmetrically in relation to each other, there being some reason to believe that all four magnetic poles lie in one hemisphere.

In view of the magnetization of the earth, resulting from influences flowing from the sun, it might be expected that the magnetic poles would constantly remain in the same relation to the sun, which would necessitate a diurnal revolution of each pole around a parallel of latitude in the neighbourhood of the Arctic and Antarctic circles respectively. We have endeavoured to show that in all likelihood the magnetic poles, or at least the centres of primary attraction in these poles, do actually describe a daily movement the longitudinal extent of which is in somewhat similar proportion to the Arctic or Antarctic circle, as the period of daily rotation is to the period of orbital revolution. The comparatively small size of the daily movement has been explained by the comparative weakness of the earth's magnetism, and the brevity of the time occupied in the daily rotation, these two causes rendering it impossible for the magnetic poles to change their geographical positions so as to remain in the same relation to the sun throughout the daily rotation. We have suggested that there is

some reason to suppose that if the daily rotation occupied the same length of time as the annual revolution occupies, the magnetic poles would, in each daily movement, describe twice the larger circle, and this may have some bearing on the formation of the two similar poles in each hemisphere which are required to explain the observed phenomena. We have seen how the combination of the orbital and axial rotations of the earth gives rise to conditions that make for magnetic changes in both intensity and direction.

Many believe that in the course of the ages, the magnetic poles do actually describe a circle around the geographical poles in the neighbourhood of the Arctic and Antarctic circles respectively; but the materials at present available are not sufficient to warrant any such conclusion; and, in any case, such a movement does not appear to be the movement of these poles in what we have described as the secular circuit.

We have endeavoured to shew that many of the peculiarities connected with terrestrial magnetism may be explained by giving due weight to (1) the influence of the two subordinate magnetic poles or foci, and (2) the want of symmetry in the geographical position of the primary magnetic poles.

Thus the position of the magnetic equator, or line of no dip, is probably fixed through the opposing influence of the magnetic poles in consequence of their want of symmetry, as affected by the minor influence of the subordinate poles. If we take the North Magnetic Pole as a centre, and describe circles of increasing size

concentrically around it till we arrive at a circle dividing the earth into two hemispheres, and if we do the same with the South Magnetic Pole, then, if we allow equal weight to the two central circles—the circles dividing the earth into two hemispheres—and, so to speak, effect a compromise between them, the resulting "circle" will aproximate closely to the magnetic equator. In fact, the resulting curve, or whatever it may be called, should, *if due weight is given to the influence of the minor foci and local causes*, be in reality the magnetic equator.

Similarly, if the two sets of circles are continued from pole to pole, the dip would be indicated by allowing a certain amount of influence to each pole, as affected in a varying degree by the minor foci, each pole being absolutely independent only in its own immediate neighbourhood. Of course, through the gradually increasing influence of each magnetic pole in its own hemisphere, the circular curves, which a compound of the two sets of circles would produce, would conform more and more nearly to true circles as the distance from the magnetic equator increased, and the distance from the pole decreased, till, in the neighbourhood of each magnetic pole, a true circle might at last reveal identity in dip.

The same reasoning would apply to the magnetic declination. In the immediate neighbourhood of each pole, its attractive power over the horizontally-balanced needle, as over the dipping needle, is virtually exclusive of the power of the opposite pole, but in every other position, when unaffected by local influences, the

declination is decided by (1) the opposing attractive power of the two magnetic poles, and (2) the varying influence of the subordinate foci. Just as the geographical position of the curves of magnetic dip—which are virtually the "parallels" of magnetic latitude—is decided by the opposing influences specified, so, we suggest, is also decided the geographical position of the lines of magnetic declination.

As both magnetic poles must have an influence in deciding the direction of the needle, except in the immediate neighbourhood of either pole, and as, in a large portion of the earth's surface, the minor foci must also have a certain influence, it must follow, that, when away from the neighbourhood of either magnetic pole, and unaffected by local causes, the needle cannot point directly towards either magnetic pole. Subject to the same exception—that is, the deviation resulting from local causes—the needle will point due north and south only when the opposing influences are so adjusted as to produce such a result. Each magnetic pole is endeavouring to attract its own end of the needle, and—subject to the exception mentioned—the opposite pole has an effect varying according to the locality.

The complex character of the opposing attractive influence of the magnetic poles and Asiatic and Southern foci, in the district of the longer magnetic meridians—the district of the "indirect" agonic lines—is evident, and we have suggested that the curious elliptical figures of "no declination" and small variation, which appear in the Northern and Southern Hemispheres

respectively, are connected with this complexity, as also with the widely differing results, in different parts of the earth, of the secular movement of the poles. We have shown too, how the phenomena of secular rotation can be explained on the basis of an elliptical pole of considerable size rotating on its axis, (or alternatively by supposing two similar poles rotating round a common centre), this suggestion receiving strong confirmation from the fact that in middle and upper northern latitudes the rate of annual change in declination is very much more rapid about the time of "no variation," than about the times of greatest variation—at which the annual movement is almost nil.

As regards the connection of terrestrial magnetism with other natural phenomena, we have pointed out that, if the earth is magnetized in the manner stated—that is, by the impact of electrical waves originated by the sun—and if sun spots are, as is believed, an indication of great solar disturbances, then it is to be expected that the electrical waves will be influenced by those disturbances, and that the resulting magnetism will thus also be affected. If the aurora is a direct result of these electrical waves, and terrestrial magnetism an indirect result, then we may well suppose that such disturbances in the centre of our system as are made apparent by the existence of large sun spots, will, when the line of force of these disturbances is towards the earth, be accompanied by auroræ of increased brilliancy, and by these violent perturbations of the magnetic needle which characterize magnetic storms.

APPENDIX.

No. I.

Referred to in Chapters IV and X.

THE recorded secular Variations in the Declination and Dip of the Magnetic Needle in London or Kew (or Greenwich), and Paris from the earliest times; collected from different authorities.

Year.	*Declination.*		*Dip.* (N)	
	London or Kew.	Paris.	London or Kew.	Paris.
	° ′	° ′	° ′	° ′
1550	11 13 E.	8 0 E.		
1576			71 50	
1580	11 17 „	11 30 „		
1600	9 16 „		72 0	
1622	6 12 „	6 30 „		
1634	4 5 „	4 16 „		
1657	0 0 „			
1664		0 40 „		
1665	1 22 W.			
1666	0 34 „	0 0 „		
1667		0 15 W.		
1671				75 0
1672	2 30 „			
1676			73 30	
1692	6 0 „			
1700	9 40 „	8 12 „		
1720	13 0 „	13 0 „		
1723	14 17 „		74 42	
1740	16 0 „	15 30 „		

Year.	Declination.		Dip. (N)	
	London or Kew.	Paris.	London or Kew.	Paris.
	° ′	° ′	° ′	° ′
1748	17 40 W.			
1754				72 15
1760	19 30 „	18 30 W.		
1773	21 9 „		72 19	
1780		19 55 „	72 8	71 48
1787	23 19 „	22 0 „		
1790	23 39 „	22 0 „	71 33	
1791				70 52
1795	23 57 „			
1800	24 36 „		70 35	
1801			70 36	
1802	24 6 „			
1805	24 8 „	22 34 „		
1806	24 8 „	21 51 „		69 12
1810				68 50
1814		22 34 „		
1815	24 27 „			
1817	24° 36′ 4″ W.			
1818	24 38 25 „	24 41 „	70 34	68 26
1819	24 36 14 „			
1820	24 34 30 „			
1821			70 3	
1822				68 19
1826				67 57
1828			69 49	
1829				67 45
1830			69 38	
1831	24 0 W.			
1835		22 24 „		67 24
1838			69° 17.60′	
1841				67 9
1850		20 31 „		66 37
1851				66 35
1854			68 31.21	
1857			68 24.87	
1858	21° 54′ 8″ W.	19 36 „	68 22.56	
1859	21 47 22 „		68 21.41	66 11
1860	21 39 51 „		68 19.29	
1861	21 31 36 „		68 17.42	
1862	21 23 32 „		68 14.89	
1863	21 13 16 „	19 0 „	68 11.71	66 1

Year.	*Declination.*		*Dip.* (N)	
	London or Kew.	Paris.	London or Kew.	Paris.
	° ′ ″	° ′	° ′	′
1864	21 3 35 W.		68 9.31	
1865	22 59 3 „		68 8.50	
1866	20 51 10 „		68 5.44	
1867	20 40 26 „		68 2.62	
1868	20 33 9 „	18 24 W.	68 2.13	65 45
1869	20 26 24 „		68 0.41	
1870	20 18 52 „		67 57.98	
1871	20 10 31 „		67 56.12	
1872	20 0 31 „		67 53.60	
1873	19 57 44 „	17 33 „	67 51.19	
1874	19 51 58 „		67 49.64	
1875	19 41 14 „			65 37
1876	19 31 53 „			65 36
1877	19 22 22 „			
1878	19 13 50 „	17 6 „		
1879	19 6 10 „	16 56 „	67 42′	65 33
1880	18 57 59 „			
1881	18 50 30 „			
1882	18 44 47 „			
	Greenwich.		Greenwich.	
1883	18° 15.0′ W.		67° 31.6′	
1884	18 8.0 „		67 30.0	
1885	18 1.7 „		67 27.8	
1886	17 54.5 „		67 27.0	
1887	17 49.1 „		67 26.4	
1888	17 40.4 „		67 25.4	
1889	17 34.9 „		67 24.9	
1890	17 28.6 „		67 22.9	
1891	17 23.4 „		67 21.4	
1892	17 17.4 „		67 19.8	
1893	17 11.4 „		67 17.8	
1894	14 4.6 „		67 17.3	
1895	16 57.0 „		67 14.7	
1896	16 52.0 „		67 15.0	
1897	16 46.0 „		67 13.0	
1898	16 39.0 „		67 12.0	
1899	16 34.2 „		67 10.2	
1900	16 29.0 „		67 8.5	
1901	16 26.0 „		67 6.1	
1902	16 22.8 „		67 3.4	
1903	16 19.1 „		67 0.9	

For certain years the figures given by different authorities vary. This is particularly the case in regard to the early dates. The following are alternative figures for the declination for London or Kew; 1580, 11° 15′ E., and "about 11½° E.;" 1622, 6° 0′ E.; 1634, 4° 6′ E.; 1820, 24° 11′ W.

It seems probable that for either 1665 or 1666 the declination given for London or Kew is incorrect, as a reverse movement is shown. The figures for the earlier of these years are from the *Encyclopædia Britannica*, and for the later from Guillemin. It is also exceedingly likely that the declination shown for either London or Paris for 1720 is erroneous, as the two are identical, this being unique. Both are so given in M. Guillemin's work. The declination for London or Kew for one or more of the years 1802, 1805, and 1806 are also evidently open to question, in respect of the latter two being identical for two succeeding years, and all showing a reverse movement of the needle on the figures given for 1800 from the general steady progression. The figures for the years 1802 and 1805 are from the *Encyclopædia Britannica*, and for 1800 and 1806 from Guillemin.

The English declination for the years from 1817 to 1820, both inclusive, are for Bushey Heath (near London), and for the years from 1858 to 1882, both inclusive, the figures, for both declination and dip in England, apply to Kew.

Although so many of the records—more especially the early ones—are open to some doubt, they, on the whole, give an accurate idea of the general movements. Possibly also, under exceptional circumstances, a year's record may, through the prevalence of magnetic storms, apparently indicate a reverse movement, or raise a doubt, when it is absolutely correct, and even in accordance with the general movement.

APPENDIX.

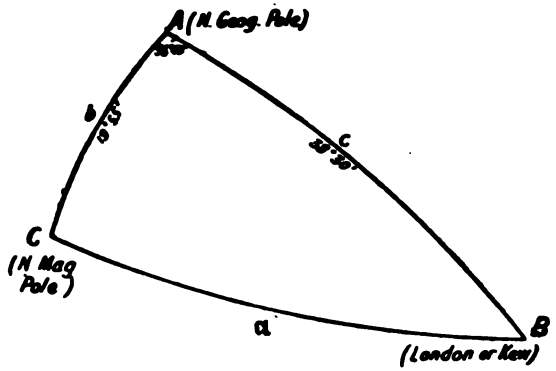
No. II.

Referred to in Chapter XX, and—as regards the first problem—in Chapter XIII.

METHOD of ascertaining the length of the diameter of the circuit daily described by the North Magnetic Pole, or the extent of its daily swing, assuming that the pole is in latitude 70° 5′ north and longitude 96° 43′ west, and that the range of its daily movement is covered by the mean semi-daily range in declination of the magnetic needle at London (or Kew), which is 28·355 minutes of arc, being the mean of the easterly and westerly movement.

Construct a triangle, one side of which *c*, is a line from London (or Kew) B, to the North Geographical Pole A, the latitude of London (or Kew) being taken as 51½° N., so that the length of this side is equal to 38½° of geographical latitude. The second side *b* is a line from the North Geographical Pole A to the North Magnetic Pole C, its length being equal to 19° 55′ of geographical latitude. The angle at the North Geographical Pole A is 96° 43′.

We have first to find the size of the angle at London (or Kew) B; and then the length of the third side *a* being the distance of the magnetic pole from London (or Kew).



a, b, and c, are expressed in degrees of geographical latitude.

To find B.

$$\tan \tfrac{1}{2}(C+B) = \frac{\cos \tfrac{1}{2}(c-b)}{\cos \tfrac{1}{2}(c+b)} \cot \tfrac{1}{2} A.$$

$$\tan \tfrac{1}{2}(C-B) = \frac{\sin \tfrac{1}{2}(c-b)}{\sin \tfrac{1}{2}(c+b)} \cot \tfrac{1}{2} A.$$

L cos $\frac{1}{2}(c-b)$ = L cos 9° 17′ = 9·9942743
L cos $\frac{1}{2}(c+b)$ = L cos 29° 12′ = 9·9409755
L sin $\frac{1}{2}(c-b)$ = L sin 9° 17′ = 9·2076795
L sin $\frac{1}{2}(c+b)$ = L sin 29° 12′ = 9·6882949
L cot $\frac{1}{2}$ A. = L cot. 48° 21′ = 9·9490987
∴ L tan $\frac{1}{2}(C+B)$ = 9·9942743 + 9·9490987 − 9·9409755.
= 10·0023975
∴ $\frac{1}{2}(C+B)$ = 45° 9′ (1)

L tan $\frac{1}{2}(C-B)$ = 9·2076795 + 9·9490987 − 9·6882949
∴ $\frac{1}{2}(C-B)$ = 16° 23′ (2)

∴ from (1) and (2) B = 28° 46′

To find a.

$$\frac{\sin a}{\sin A} = \frac{\sin b}{\sin B}$$

$\therefore$ L sin a = L sin A + L sin b − L sin B.

= L sin 96° 43′ + L sin 19° 55′ − L sin 28° 46′

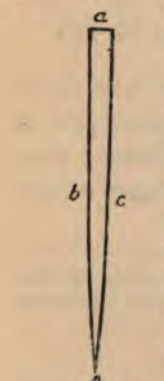
= L sin 83° 17′ + L sin 19° 55′ − L sin 28° 46′

= 9·9970090 + 9·5323123 − 9·6823651

= 9·8469562

Therefore a = either 44° 40′ or 180° − 44° 40′, that is 135° 20′. It is evident that in this particular problem the first of these alternative answers is the correct one, and that a is therefore equal to 44° 40′.

We now construct another triangle, the first side of which c is a line from London (or Kew) A, to one side of the range of the small daily movement, the length being, as we have just found, equal to 44° 40′ of geographical latitude. The second side is a line from London (or Kew) to the other end of the range of the daily movement, the length of this side b being taken as practically the same as the first side. The angle at London (or Kew) A, is 28·355′, being the semi-range in declination of the needle's movement, on the daily average—but as we have not been able to calculate the length of the given sides of the triangle to a lower denomination than the minutes, we may ignore the decimal part, and take the angle at London (or Kew) A as being 28′.



We have now to find the length of the third side a, which will be approximately the actual geographical length of the range of the daily movement.

To find the value of a.

$$\cos a = \cos b \cos c + \sin b \sin c \cos A.$$

$$\therefore \cos a = \cos^2 c + \sin^2 c \cos A.$$

$$= 1 - \sin^2 c + \sin^2 c \cos A.$$

$$\therefore 1 - \cos a = \sin^2 c\,(1 - \cos A.)$$

$$\therefore \sin^2 \frac{a}{2} = \sin^2 c \sin^2 \frac{A}{2}$$

$$\therefore \mathrm{L} \sin \frac{a}{2} = \mathrm{L} \sin c + \mathrm{L} \sin \frac{A}{2} - 10$$

$$\because \mathrm{L} \sin \frac{a}{2} = \mathrm{L} \sin 44^\circ\ 40' + \mathrm{L} \sin 14' - 10$$

$$= 9{\cdot}8469562^* + 7{\cdot}6098530 - 10$$

$$= 7{\cdot}4568092$$

$$\therefore \frac{a}{2} = \text{nearly } 10'. \quad \therefore a = \text{nearly } 20' \text{ (say } 19'\ 40'')$$

We may therefore take the diameter of the daily circuit or the extent of the daily swing of the magnetic pole, or centre of primary attraction, as being approximately equal to 19′ 40″, which is nearly one-third of a degree of geographical latitude.

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* We use here not log, 44° 40′ but log sin a of the preceding question, which of course is very near log 44° 40′, the latter being the nearest log, in minutes, to log sin a of the preceding question.

APPENDIX.

No. III.

Referred to in Chapter XIII.

METHOD of ascertaining the angle of variation which would be produced at London if the needle were attracted to the *south* magnetic pole, and the latter were situated in latitude 73½ degrees south, and longitude 64° 13′ west, that longitude corresponding with the longitudinal want of symmetry of the South Magnetic Pole in relation to the North Magnetic Pole.

a, *b*, and *c*, are expressed in degrees of geographical latitude *a* =16½° of Lat. B=64° 13′.

Construct a triangle one side of which *c* is a line from London A to the South Geographical Pole B, the latitude of London being taken as 51½ degrees north, so that the length of this side is equal to 141½ degrees of geographical latitude. The second side *a* is a line from the South Geographical Pole B to the South Magnetic Pole C, its length being equal to 16½ degrees of geographical latitude. The angle at the South Geographical Pole B is 64° 13′. We have to find the angle A at London, and thereafter the length of the third side *b*, being the distance from London to the South Magnetic Pole C.

To find A.

$$\tan \tfrac{1}{2}(C + A) = \frac{\cos \frac{1}{2}(c-a)}{\cos \frac{1}{2}(c+a)} \cot \tfrac{1}{2} B$$

$$\tan \tfrac{1}{2}(C - A) = \frac{\sin \frac{1}{2}(c-a)}{\sin \frac{1}{2}(c+a)} \cot \tfrac{1}{2} B$$

$\text{L} \cos \frac{1}{2}(c-a) = \text{L} \cos 62° 30' = 9{\cdot}6644056$

$\text{L} \cos \frac{1}{2}(c+a) = \text{L} \cos 79° = 9{\cdot}2805988$

$\text{L} \sin \frac{1}{2}(c-a) = 9{\cdot}9479289$

$\text{L} \sin \frac{1}{2}(c+a) = 9{\cdot}9919466$

$\text{L} \cot \frac{1}{2} B = \text{L} \cot 32° 6'$

$= 10{\cdot}2025255$

$\therefore \text{L} \tan \frac{1}{2}(C+A) = 9{\cdot}6644056 + 10{\cdot}2025255 - 9{\cdot}2805988$

$= 10{\cdot}5863323$

$\therefore \frac{1}{2}(C+A) = 75° 28' \qquad (1)$

$\text{L} \tan \frac{1}{2}(C-A) = 9{\cdot}9479289 + 10{\cdot}2025255 - 9{\cdot}9919466$

$= 10{\cdot}1585078$

$\therefore \frac{1}{2}(C-A) = 55° 14' \qquad (2)$

$\therefore$ from (1) and (2). $A = 20° 14'$

To find b.

$$\frac{\sin b}{\sin B} = \frac{\sin a}{\sin A}$$

$\therefore \text{L} \sin b = -\text{L} \sin A + \text{L} \sin a + \text{L} \sin B$

$= -\text{L} \sin 20° 14' + \text{L} \sin 16° 30' + \text{L} \sin 64° 13'$

$= -9{\cdot}5388804 + 9{\cdot}4533418 + 9{\cdot}9544574$

Therefore b = either 47° 41′ or 180° − 47° 41′.

It is evident that in this particular problem the second of these alternative answers is the correct one, and that b is therefore equal to 132° 19′.

Therefore the angle of variation at London, under the circumstances specified, would be 20° 14′; and the distance of the South Magnetic Pole from London would be 132° 19′.

APPENDIX.

No. IV.

Referred to in Chapter XVI.

CALCULATIONS as to the daily time of nearest approach of the North Magnetic Pole to certain stations in the Northern Hemisphere, on the supposition that the pole, or at least its centre of primary attraction, describes a daily circuit, and that the dip of the needle is primarily affected by the approach and recession of the pole, or its centre of primary attraction, in this circuit.

Jan Mayen is in latitude 71° 0′ N. and longitude 8° 28′ W., and the North Magnetic Pole is believed to be in latitude 70° 5′ N. and longitude 96° 43′ W. In order to calculate at what portion of its conjectured daily circuit the magnetic pole, or the centre of primary attraction, would be at its nearest distance to Jan Mayen, we shall suppose the daily circuit to be represented by a dial numbered around the circumference from 1 to 24, corresponding with the 24 hours of the solar day. We shall assume that the figure 10 is the nearest part of the dial to the North Geographical Pole, and consequently, that the figure 22 is the most southern part, and also that, with the figures on the dial placed as specified,

the hours approximate to Greenwich time. Thus, when the source of attraction is passing over the figure 10 in its daily circuit, and is therefore at its nearest distance for the day to the North Geographical Pole, the time in Greenwich will be about 10 a.m.

On these assumptions let us calculate at what part of its daily circuit the attractive influence will, when in the latitude and longitude specified, be at its nearest distance to Jan Mayen. It is taken for granted that as Jan Mayen is in a higher latitude than the magnetic pole itself, 10 o'clock would mark the nearest part of the circuit, were the magnetic pole situated either on the same meridian as Jan Mayen or on the opposite meridian. We shall first calculate what would be the nearest part of the circuit with the magnetic pole 90° west of Jan Mayen, that is, in longitude 98° 28′ W.

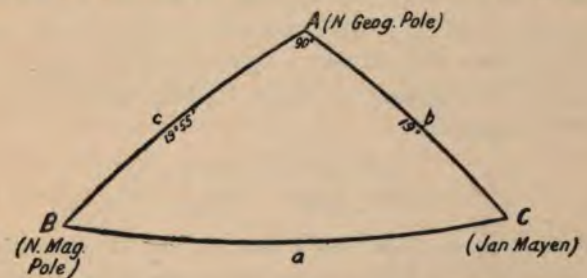
Let us construct a triangle of which the angles shall represent Jan Mayen, the North Magnetic Pole, and the North Geographical Pole, respectively. The length of the side extending from Jan Mayen to the North Geographical Pole, will be 19° of geographical latitude; and, with the magnetic pole in latitude 70° 5′ N., the side extending from the North Geographical Pole to the North Magnetic Pole will be 19° 55′ of geographical latitude. Let A stand for the North Geographical Pole; B for the North Magnetic Pole; and C for Jan Mayen. With the North Magnetic Pole 90° west of Jan Mayen, the angle at A will be a right angle.

We have to find the angle at B.

$$\begin{aligned}
\sin c &= \cot B \tan b \\
\therefore \cot B &= \sin c \cot b \\
\therefore \mathrm{L}\cot B &= \mathrm{L}\sin c + \mathrm{L}\cot b - 10 \\
&= \mathrm{L}\sin 19^\circ\ 55' + \mathrm{L}\cot 19^\circ - 10 \\
&= 9{\cdot}5323123 + 10{\cdot}4630281 - 10 \\
&= 9{\cdot}9953404
\end{aligned}$$

Therefore the angle at B is equal to 45° 18′.

Now it is clear, from the basis of the problem, that the line B A, which extends between the Magnetic and Geographical



a, *b*, and *c*, are expressed in degrees of geographical latitude.

Poles, commences at the *centre* of the conjectured daily circuit of the Magnetic Pole, and passes *through the figure* 10 on the dial. The nearest part of the daily circuit to Jan Mayen in the position specified, is thus separated from the figure 10 by an angle, on the circumference of the daily circuit, of 45° 18′; and, from the fact that the figures on the dial are represented clock-wise as described, this angle is between the figure 10 and the higher figures.

Now the figure 16 is separated from the figure 10 by one quarter of the circumference of the daily circuit, the angular separation being therefore 90°. If then an angle of 90°

represents a separation of 6 hours, what does an angle of 45° 18′ represent?

90° : 45° 18′ : : 6h. : ?
5400′ : 2718′ : : 360m. : ?

The answer is 181 minutes and a fraction, which, ignoring the fraction, is 3h. 1m. Thus the part of the dial nearest to Jan Mayen in the circumstances specified, is separated from the figure 10 in the direction of the higher figures, by 3h. 1m., and is therefore 13h. 1m.

This calculation is based on the magnetic pole being situated 90° west of Jan Mayen; but as Jan Mayen is in longitude 8° 28′ W., the separation is only 88° 15′, being 1° 45′ less than 90°. If then a separation of 90° represents a change of 3h. 1m. from the figure 10, what will a separation of 88° 15′ represent?

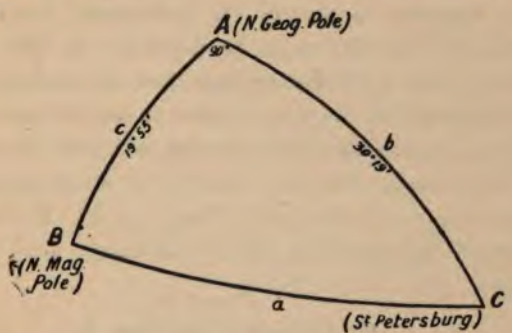
90° : 88° 15′ : : 3h. 1m. : ?
5400′ : 5295 : : 181m. : ?

The answer is 177m. and a fraction, say 177m.,—that is, 2h. 57m. The part of the daily circuit nearest to Jan Mayen would therefore, in the circumstances stated, be separated from the figure 10 by 2h. 57m., the separation being in the direction of the larger figures. This gives us 12h. 57m., so that the magnetic pole, or the centre of primary attraction, should, according to this calculation, be at its nearest distance to Jan Mayen for the day, about 12h. 57m. p.m.

ST. PETERSBURG.

The other stations with which we are dealing all lie in lower latitudes than the magnetic pole, so that it seems reasonable to assume that the figure 22 would be the nearest part of the daily circuit, with the magnetic pole on the same meridian as

the observing station, and the figure 10 the nearest part with the magnetic pole on the opposite meridian. Let us calculate what would be the nearest part of the daily circuit to St. Petersburg—which is in latitude 59° 41′ N., and longitude 30° 29′ E.—supposing the magnetic pole to be situated longitudinally 90° west of St. Petersburg. Construct a triangle, the angles of which shall represent the North Magnetic Pole, the North Geographical Pole, and St. Petersburg, respectively, the angle at the North Geographical Pole being a right angle.



a, *b*, and *c*, are expressed in degrees of geographical latitude.

We have to find the angle at B.

$$\begin{aligned} \text{L cot B} &= \text{L sin } c + \text{L cot } b - 10 \\ &= \text{L sin } 19^\circ\ 55' + \text{L cot } 30^\circ\ 19' - 10 \\ &= 9{\cdot}5323123 + 10{\cdot}2330349 - 10 \\ &= 9{\cdot}7653472 \end{aligned}$$

Therefore the angle at B is equal to 59° 47′; and, as the line B A passes through the figure 10, this is the angular distance by which the part of the daily circuit nearest to St. Petersburg, in the given circumstances, is separated from the figure 10, in the direction of the higher figures.

Taking it, as formerly that the figure 16 represents an angular separation from 10, of 90°, we find that, proportionally, the angle 59° 47′ represents a separation from 10, of 3h. 59m.; so that the nearest part of the circuit to St. Peterburg would be 1h. 59m. p.m. (13.59). But the magnetic pole is actually 127° 12′ west of St. Petersburg, an excess over 90° of 37° 12′.

We have assumed that if the magnetic pole were on the meridian opposite to that of St. Petersburg, the nearest part of the daily circuit would be the figure 10, and, as the opposite meridian is 90° farther west than the meridian upon which we have placed the magnetic pole, in our last calculation, we see that a displacement of the magnetic pole, 90° farther to the west, would shift the nearest part of the circuit by 3h. 59m., changing it from 13h. 59m. to 10h. If then 90° represents a change of 3h. 59m., what change does 37° 12′ represent?

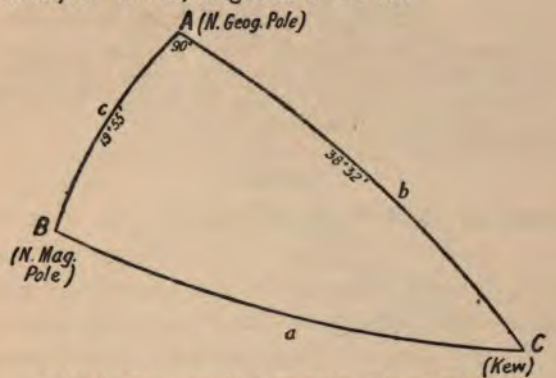
90° : 37° 12′ : : 3h. 59m. : ?
5400′ : 2232′ : : 239m. : ?

The answer is 99m. (1h. 39m.), which is therefore the amount by which the nearest part of the daily circuit will be shifted from 13h. 59m., in the direction of the figure 10, by the removal of the magnetic pole from 90° west of St. Petersburg to 127° 12′ west of it. The part of the daily circuit nearest to St. Petersburg, with the magnetic pole in longitude 96° 43′ W., would therefore be 12h. 20m.

The following are the corresponding calculations for the other three stations:—

KEW.

Latitude, 51° 28′ N., longitude 0° 19′ W.



a, *b*, and *c*, are expressed in degrees of geographical latitude.

To find the angle at B.

$$\begin{aligned} \text{L cot B} &= \text{L sin } c + \text{L cot } b - 10 \\ &= \text{L sin } 19° 55′ + \text{L cot } 38° 32′ - 10 \\ &= 9{\cdot}5323123 + 10{\cdot}0988763 - 10 \\ &= 9{\cdot}6311886 \\ \therefore \text{B} &= 66° 50′ \end{aligned}$$

To find the distance in time by which that angle is separated from the figure 10, on the dial representing the magnetic pole's daily circuit—the separation being towards the larger figures:—

$$90° : 66° 50′ :: 6\text{h.} : ?$$
$$5400′ : 4010′ :: 360\text{m.} : 267\ \tfrac{18}{54}\text{m.}$$

Thus, with the magnetic pole 90° west of Kew, the nearest part of the daily circuit would be separated from 10 o'clock, in the direction of the larger figures, by 4h. 27m., that is to say, it would be 14h. 27m.

With the magnetic pole in longitude 96° 43′ W., it is 96° 24′ west of Kew, the excess over 90° west of Kew being thus 6° 24′; the change of position of the portion of the dial

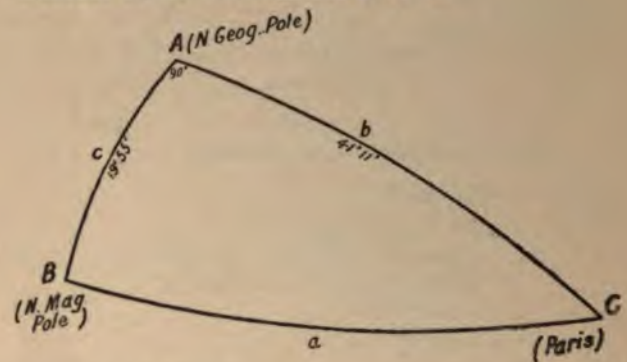
nearest to Kew, resulting therefrom, is found by the following proportion.

$$90° : 6° 24' : : 4h.\ 27m. : ?$$
$$5400 : 384 : : 267m. : 19m.$$

Thus the nearest part of the daily circuit is altered by 19m. in the direction of the figure 10, making it 14h. 8m.; that is, 2h. 8m. p.m.

PARIS.

Latitude 48° 49′ N., longitude 2° 29′ E.



a, *b*, and *c*, are expressed in degrees of geographical latitude.

To find the angle at B.

$$\begin{aligned} \text{L cot B} &= \text{L sin } c + \text{L cot } b - 10 \\ &= \text{L sin } 19° 55' + \text{L cot } 41° 11' - 10 \\ &= 9{\cdot}5323123 + 10{\cdot}0580316 - 10 \\ &= 9{\cdot}5903439 \end{aligned}$$
$$\therefore \text{B} = 68° 44'$$

To find the distance in time by which that angle is separated from the figure 10, on the dial representing the daily circuit, the separation being towards the larger figures.

$$90° : 68° 44' : : 6h. : ?$$
$$5400' : 4124' : : 360m. : 274\ \tfrac{504}{840}\text{m.}$$

Thus with the magnetic pole 90° west of Paris, the nearest

part of the daily circuit would be separated from 10 o'clock, in the direction of the larger figures, by 4h. 35m., that is to say it would be 14h. 35m.

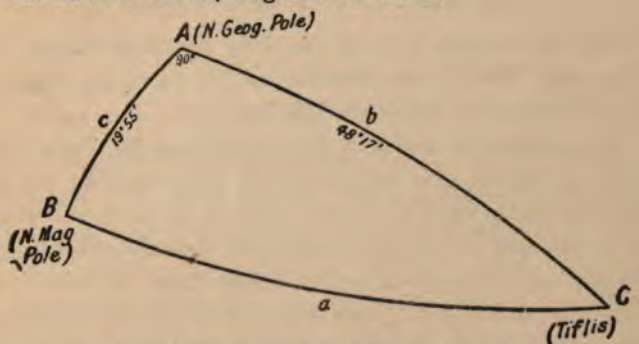
With the magnetic pole in longitude 96° 43′ W., it is 99° 12′ west of Paris, the excess over 90° west of Paris being thus 9° 12′. The change of position of the portion of the dial nearest to Paris, resulting therefrom, is found by the following proportion :—

$$90° : 9° 12′ : : 4\text{h. } 35\text{m.} : ?$$
$$5400′ : 552 \quad : : 275\text{m.} : 28\text{m.}$$

Thus the nearest part of the daily circuit is altered by 28m. in the direction of the figure 10, making the nearest part of the circuit 14h. 7m., that is, 2h. 7m. p.m.

TIFLIS.

Latitude 41° 43′ N., longitude 44° 48′ E.



a, *b*, and *c*, are expressed in degrees of geographical latitude

To find the angle at B.

$$\text{L cot B} = \text{L sin } 19° 55′ + \text{L cot } 48° 17′ - 10$$
$$= 9{\cdot}5323123 + 9{\cdot}9501162 - 10$$
$$= 9{\cdot}4824285$$
$$\therefore \text{B} = 73° 6′$$

To find the distance in time by which that angle is separated from the figure 10, on the dial representing the daily circuit, the separation being towards the larger figures.

$$90° : 73° 6' :: 6h. : ?$$
$$5400' : 4386' :: 360m. : 292\tfrac{216}{540}m.$$

Thus with the magnetic pole 90° west of Tiflis, the nearest part of the daily circuit would be separated from 10 o'clock, in the direction of the larger figures, by 4h. 52m., that is to say, it would be 14h. 52m.

With the magnetic pole in longitude 96° 43′, it is 141° 31′ west of Tiflis, the excess over 90° west of Tiflis being thus 51° 31′. The change of position of the portion of the dial nearest to Tiflis, resulting therefrom, is found by the following proportion:—

$$90° : 51° 31' :: 4h. 52m. : ?$$
$$5400' : 3091' :: 292m. : 167m.$$

Thus the nearest part of the daily circuit is altered by 167m. (2h. 47m.), in the direction of the figure 10, making the nearest part of the circuit 12h. 5m.

As explained in the text, the calculations for Paris and Tiflis are based upon very uncertain data, and the dip at Tiflis appears to be decided not simply by the daily circuit at the North Magnetic Pole, but also, and in combination therewith, by the daily circuit at the Asiatic focus, to which it is much nearer, being longitudinally only 65°, or thereby, from its supposed longitude, compared with 141° from the North Magnetic Pole.

APPENDIX.

No. V.

Referred to in Chapter XVIII.

Deviations from the general progress of change in declination, and table of secular magnetic changes at certain European stations, some of which present contrasts to others as regards the general progress of the declination.

It is mentioned in the text that—owing, no doubt, chiefly to local causes—there are frequently large deviations in declination in places not far removed from one another, so that the lines of declination shown on magnetic charts are merely the approximate average of the locality. We have compiled the following table from the figures given by Dr. G. D. E. Weyer, and it is illustrative of this fact. We have seen that the line of "no variation" passed through London in 1657, apparently travelling eastwards; but it would be a matter of the utmost complexity to trace the gradual secular change of this line in conformity with the dates of "no variation" as given by Dr. Weyer. Although his figures

are, doubtless, only approximately correct, there is no reason to suppose that this complexity is a result of any errors. Even with absolute accuracy in his tables such complexity would evidently exist. It would thus appear that the agonic lines shown on present day magnetic charts must necessarily be different, not only in geographical position, but also in general outline, from the agonic lines of, say, 250 years ago.

The agonic line which passed through London in 1657—or according to Weyer, in 1658—reached Berlin in 1660, being the year previous to its arrival in Paris, although Paris lies considerably to the west of Berlin, and only a comparatively small distance to the east of London. It would seem also that this agonic line appeared in Brussels—which lies longitudinally about one-third of the distance of Berlin east of London, and which is less than a degree south of London—in 1648, being (according to Weyer's figures) actually 10 years earlier than it reached London, and 12 years earlier than it reached Berlin. Apparently, also, "no variation" occurred at Dantzig, which is somewhat over 200 miles north-east of Berlin, in 1617, which is 43 years earlier than it occurred in Berlin itself, notwithstanding that the general travel of the agonic line appears to have been in an easterly, and not a westerly direction.

It would seem that at Copenhagen, Stockholm, and Tornea —which all lie on, or in the neighbourhood of, a line running N.N.E. and S.S.W.—the needle never points to the true north at all, but has a permanent westerly variation. These peculiarities and deviations from the general system would seem to be occasioned, at least to a great extent, by local causes.

TABLE OF SECULAR MAGNETIC CHANGES AT CERTAIN EUROPEAN STATIONS, SOME OF WHICH PRESENT CONTRASTS TO OTHERS AS REGARDS THE GENERAL PROGRESS OF THE DECLINATION.

Station.	Date of No Variation.	Date of Extreme Westerly Declin.	Date of Extreme Easterly Declin.	Date of Mean Position.	Mean Declin. Westerly.	Total Range of Declin.
Lisbon 38° 42′ N. 9° 5′ W.	1674 1984	1829	1584	1706	6½°	32¼°
Brest 48° 22′ N. 4° 32′ W.	1672 1976	1824	1584	1704	7¼	35½
Plymouth 50° 23′ N. 4° 10′ W.	1676 1976	1825	1575	1700	5⅞	38⅜
London 51° 28′ N. 0° 19′ W.	1658 1973	1816	1560	1688	6¼	35¼
Paris 48° 49′ N. 2° 29′ E.	1661 1967	1814	1574	1694	6⅜	31½
Brussels 50° 51′ N. 4° 22′ E.	1648 1961	1805	1535	1670	4½	37¼
Bergen 60° 23′ N. 5° 29′ E.	1680 1956	1818	1608	1713	7⅜	32⅜
Christiania 59° 54′ N. 10° 45′ E.	1681 1950	1822	1612	1923	6	28
Nuremberg 49° 26′ N. 11° 6′ E.	1658 1973	1802	1557	1680	6¼	29⅜
Copenhagen 55° 41′ N. 12° 36′ E.	Never.	1811	1651	1571 1731	10½	16
Berlin 52° 30′ N. 13° 23′ E.	1660 1943	1800	1550	1676	3	30
Stockholm 59° 20′ N. 18° 0′ E.	Never.	1812	1692	1632 1752	10¼	11½
Dantzig 54° 21′ N. 18° 41′ E.	1617 1975	1787	1517	1652	4¼	22¼
Konigsberg 54° 43′ N. 20° 30′ E.	1621 1950	1785	1545	1665	5	18¼
Tornea 65° 51′ N. 24° 14′ E.	Never.	1803	1569 1725	1607 1685	9	10⅜
St. Petersburg 59° 41′ N. 30° 29′ E.	1620 1696 1890	1793	1658	1591 1726	3¼	10½

APPENDIX.

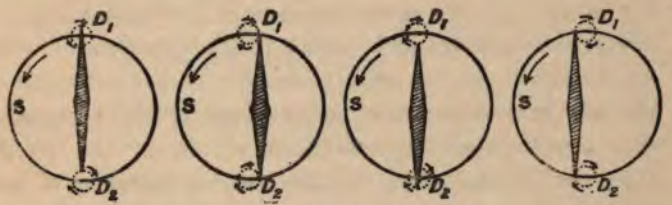
No. VI.

Referred to in Chapter XX.

The relation between the hypothetical daily and secular movements of the Magnetic Poles.

We have, in dealing with the daily movement of the magnetic poles — and more particularly, of course, of the North Magnetic Pole — found that the daily movements of the needle indicate the occurrence, at the pole primarily affecting it, of a daily circular movement. It has, however, been suggested that the daily movement of the magnetic pole as a whole, may have more of the character of a swing than a revolution; although the movements of the needle indicate that a circle is described by "the centre of primary attraction." It has also been suggested, and, as we have seen, the available evidence supports the suggestion, that the magnetic poles are in reality elliptical in shape, and that the secular movement is really a revolution of this elliptical pole on its axis, as if it revolved on a "pivot." The evidence does not indicate that the magnetic pole as a whole changes its geographical position to any considerable extent other than can be reasonably accounted for by the supposition of a revolution on its axis. If then the secular movement of the pole is virtually an axial revolution, it is clear that the daily movement—which is almost inappreciable in comparison with the secular movement—can by no means be a revolution of the pole as a whole.

How then can we account for a daily circular movement, such as is indicated by the daily changes in declination and dip, and, at the same time, allow of the secular revolution of the pole as a whole? It is manifest that if the secular movement is as described, the portion of that movement applicable to one day would be merely a slight swing on the circumference of the secular circuit.



S Secular Circuit of Poles.
D_1, D_2, Daily, „ „

The double movement may reasonably be explained by allowing a certain amount of freedom at the "axis." We have spoken of the magnetic pole as being, as it were, "pivoted" at the centre. The daily and secular movements appear to be quite consistent with each other if we allow for a certain amount of "play" at the "pivot"; so that the pole as a whole is free to move to a limited extent both in latitnde and longitude. We have found that the daily revolution appears to be clockwise, and the secular revolution in the reverse direction. We may illustrate the two movements, in conformity with the explanations we have suggested, by the diagrams shown above.

The large circles represent the secular circuit, and the small circles—which of course have to be shown on a very large and disproportionate scale for the sake of clearness—represent the

Taking it, as formerly that the figure 16 represents an angular separation from 10, of 90°, we find that, proportionally, the angle 59° 47′ represents a separation from 10, of 3h. 59m.; so that the nearest part of the circuit to St. Peterburg would be 1h. 59m. p.m. (13.59). But the magnetic pole is actually 127° 12′ west of St. Petersburg, an excess over 90° of 37° 12′.

We have assumed that if the magnetic pole were on the meridian opposite to that of St. Petersburg, the nearest part of the daily circuit would be the figure 10, and, as the opposite meridian is 90° farther west than the meridian upon which we have placed the magnetic pole, in our last calculation, we see that a displacement of the magnetic pole, 90° farther to the west, would shift the nearest part of the circuit by 3h. 59m., changing it from 13h. 59m. to 10h. If then 90° represents a change of 3h. 59m., what change does 37° 12′ represent?

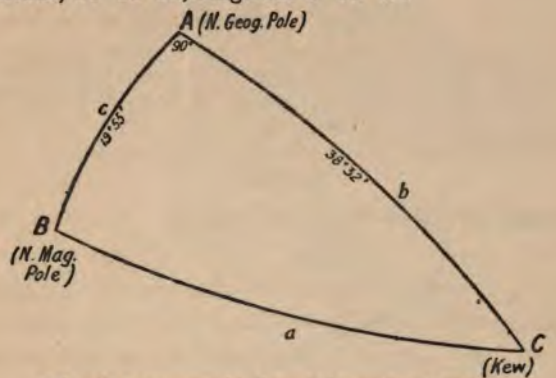
90° : 37° 12′ : : 3h. 59m. : ?
5400′ : 2232′ : : 239m. : ?

The answer is 99m. (1h. 39m.), which is therefore the amount by which the nearest part of the daily circuit will be shifted from 13h. 59m., in the direction of the figure 10, by the removal of the magnetic pole from 90° west of St. Petersburg to 127° 12′ west of it. The part of the daily circuit nearest to St. Petersburg, with the magnetic pole in longitude 96° 43′ W., would therefore be 12h. 20m.

The following are the corresponding calculations for the other three stations:—

KEW.

Latitude, 51° 28′ N., longitude 0° 19′ W.



a, *b*, and *c*, are expressed in degrees of geographical latitude.

To find the angle at B.

$$\begin{aligned} \text{L cot B} &= \text{L sin } c + \text{L cot } b - 10 \\ &= \text{L sin } 19^\circ\ 55' + \text{L cot } 38^\circ\ 32' - 10 \\ &= 9{\cdot}5323123 + 10{\cdot}0988763 - 10 \\ &= 9{\cdot}6311886 \\ \therefore \text{B} &= 66^\circ\ 50' \end{aligned}$$

To find the distance in time by which that angle is separated from the figure 10, on the dial representing the magnetic pole's daily circuit—the separation being towards the larger figures:—

$$90^\circ : 66^\circ\ 50' :: 6\text{h.} : ?$$
$$5400' : 4010' :: 360\text{m.} : 267\ \tfrac{18}{54}\text{m.}$$

Thus, with the magnetic pole 90° west of Kew, the nearest part of the daily circuit would be separated from 10 o'clock, in the direction of the larger figures, by 4h. 27m., that is to say, it would be 14h. 27m.

With the magnetic pole in longitude 96° 43′ W., it is 96° 24′ west of Kew, the excess over 90° west of Kew being thus 6° 24′; the change of position of the portion of the dial

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To find the distance in time by which that angle is separated from the figure 10, on the dial representing the daily circuit, the separation being towards the larger figures.

$$90° : 73° 6' : : 6h. : ?$$
$$5400' : 4386' : : 360m. : 292\tfrac{216}{340}m.$$

Thus with the magnetic pole 90° west of Tiflis, the nearest part of the daily circuit would be separated from 10 o'clock, in the direction of the larger figures, by 4h. 52m., that is to say, it would be 14h. 52m.

With the magnetic pole in longitude 96° 43', it is 141° 31' west of Tiflis, the excess over 90° west of Tiflis being thus 51° 31'. The change of position of the portion of the dial nearest to Tiflis, resulting therefrom, is found by the following proportion:—

$$90° : 51° 31' : : 4h. 52m. : ?$$
$$5400' : 3091' : : 292m. : 167m.$$

Thus the nearest part of the daily circuit is altered by 167m. (2h. 47m.), in the direction of the figure 10, making the nearest part of the circuit 12h. 5m.

As explained in the text, the calculations for Paris and Tiflis are based upon very uncertain data, and the dip at Tiflis appears to be decided not simply by the daily circuit at the North Magnetic Pole, but also, and in combination therewith, by the daily circuit at the Asiatic focus, to which it is much nearer, being longitudinally only 65°, or thereby, from its supposed longitude, compared with 141° from the North Magnetic Pole.

APPENDIX.

No. V.

Referred to in Chapter XVIII.

Deviations from the general progress of change in declination, and table of secular magnetic changes at certain European stations, some of which present contrasts to others as regards the general progress of the declination.

It is mentioned in the text that—owing, no doubt, chiefly to local causes—there are frequently large deviations in declination in places not far removed from one another, so that the lines of declination shown on magnetic charts are merely the approximate average of the locality. We have compiled the following table from the figures given by Dr. G. D. E. Weyer, and it is illustrative of this fact. We have seen that the line of "no variation" passed through London in 1657, apparently travelling eastwards; but it would be a matter of the utmost complexity to trace the gradual secular change of this line in conformity with the dates of "no variation" as given by Dr. Weyer. Although his figures

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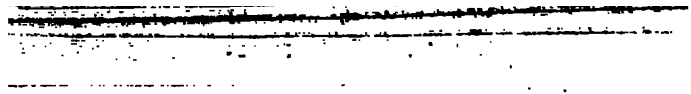
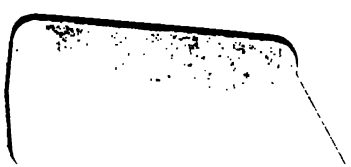
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